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AN IMPROVED GROUND VIBRATION TEST METHOD

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Research was conducted to develop an improved method for ground vibration testing of airplanes. The resulting method, a single point excitation-frequency response analysis method, utilizes the computer, modern electronic equipment, developments in vibration testing theory and improvements in mechanical system design to accomplish ground vibration tests at greatly reduced cost while significantly improving accuracy. A demonstration ground vibration test was conducted using the improved method on an A-10 Airplane.

PREFACE

The research reported in this document was conducted by The Boeing Company for the Air Force Wright Aeronautical Laboratories under Air Force Contract F33615-77-C-3059, "Optimum Ground Vibration Test Method." Otto F. Maurer was the Air Force Technical Monitor for the contract. Bennie F. Dotson was the Program Manager, Roman F. Michalak was the Principal Investigator for Phase I and David W. Gimmestad was the Principal Investigator for Phases II and III at Boeing Military Airplane Company. Carl S. Doherty was the Lead Engineer, and significant contributions were made by Rita M. Nadreau, at the Vibration Laboratory of Boeing Commercial Airplane Company. At the University of Cincinnati, subcontractor to Boeing in this research, Dr. David L. Brown was Principal Investigator with significant contributions from Randall J. Allemang and Ray Zimmerman.

The body of this report was written by Roman F. Michalak, David L. Brown, Randall J. Allemang and David W. Gimmestad. Appendix A, the "Guide for Ground Vibration Testing of Airplanes" was written by Carl S. Doherty and Rita M. Nadreau. Appendix B, the "Aircraft Soft Support System" was written by David W. Gimmestad.

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LIST OF SYMBOLS

SYMBOL	
ζ	Damping Coefficient
δ	Decay Rate
ω	Frequency
x_p	Displacement at Location p
F_q	Applied Force at Location q
j	$\sqrt{-1}$
U	Real Part of Modal Amplitude
V	Imaginary Part of Modal Amplitude
ϕ	Phase Angle
A	Residue
s	Laplace Variable
h	Impulse Response Function
t	Time
H	Frequency Response Function

SUMMARY

The development of an improved aircraft ground vibration testing method is discussed. This method, a single point excitation-frequency response analysis method, greatly reduces the cost of ground vibration testing while offering significant improvements in accuracy. The development of this improved method begins with a description of the testing philosophy and objectives of ground vibration testing at airframe manufacturers in the United States, followed by a description of the ground vibration test. The state of the art review includes a broadly based literature survey. The industry interviews reveal areas where the airframe industry, with exceptions, is behind the state of the art, and shows opportunities for rapid improvement.

The single point excitation-frequency analysis method separates the ground vibration test into a measurement phase and an analysis phase. The measurement phase is conducted on the test site, and results in measurements of excitation and response. The analysis phase is conducted in the laboratory computer room, and results in frequency response functions and modal characteristics. Recommendations include methods for ground vibration testing and specific equipment items to improve the test.

Recommendations are also made for future research and development and for approaches by which ground vibration testing improvements may be applied to USAF programs. A demonstration ground vibration test was conducted using the recommended method. This test on an A-10 airplane is reported in Volume II of this report. A "Guide for Ground Vibration Testing of Airplanes," which incorporates the recommended method is also included in an appendix.

1.0 INTRODUCTION

Ground vibration testing is an important element in the development of airplane structures. Knowledge of the dynamic characteristics of an aircraft is needed to analyze gust loads, flutter, shimmy, stability and control, maneuver loads, buffet loads, environmental vibration, ride comfort, acoustics, taxi loads, landing loads, etc. Calculating the dynamic characteristics is a complicated process which is done during preliminary design and final design of an airplane. The Ground Vibration Test is necessary to insure that the dynamic characteristics used in all the dynamic analyses are correct.

The opportunity for a significant improvement in ground vibration testing occurred when advances in a number of the vibration testing detail techniques had improved. These advances were the result of incorporating the computer into the test equipment, developments in integrated electronic circuitry, developments in vibration testing theory and improvements in mechanical system design. Selection of the methodology for this improved ground vibration testing method, integration of advances in detailed techniques into this method, some further advances and a demonstration of this improved method constituted the reported research.

The discussion in this report begins with testing philosophy and objectives. The testing philosophy and objectives of vibration testing as practiced in the United States, and by the airframe industry in particular, is defined. The description of a ground vibration test follows, in which its differentiation into measurement and analysis phases, and its goals and assumptions are discussed.

The state of the art review draws from a literature review, industry interviews and in-house experience. The review first discusses the general methods used in vibration testing, then reviews specific techniques used in ground vibration testing and the characteristics of modal parameter estimation. The process for selection of a recommended ground vibration testing (GVT) method follows. The candidate methods are rated by several criteria and analytical studies of the modal estimation process are discussed.

The recommended ground vibration testing method, the single point excitation-frequency response analysis method, is described in detail. The measurement phase and the interpretation phase of a test conducted by this method are outlined.

Conclusions are drawn on the current state of the art and on the recommended GVT method. Recommendations on ground vibration test method are made. Also the use of certain items of equipment is recommended for use in a GVT. Research and development recommendations which would further improve the GVT are made. Finally recommendations are made on applying the GVT improvements.

The appendices include a "Guide for Ground Vibration Testing of Airplanes" which incorporates the recommended method and Volume II contains the "A-10 Demonstration GVT Test Report." The latter report documents a demonstration GVT that was conducted using the recommended method. An appendix discusses design and development of an aircraft soft support system that was fabricated for use in the demonstration GVT.

2.0 DISCUSSION

2.1 TESTING PHILOSOPHY AND OBJECTIVES

An airplane ground vibration test is a test performed on an airplane to measure its structural dynamic characteristics. The principal reason for conducting a GVT is usually to support the flutter clearance program, a critical safety of flight item. Other important problem areas supported by the GVT include gust loads, shimmy, stability and control, maneuver loads, buffet loads, environmental vibration, ride comfort, acoustics, taxi loads and landing loads.

In the flutter clearance program a mathematical model of the airplane is usually developed. This model is the flutter engineer's abstraction of the mass and stiffness characteristics of the airplane. The objective of the ground vibration test is to provide data to validate, improve or replace the mathematical model.

The quality of the finished test data must be adequate for the engineering task it is needed for. Concurrent with this, the resources expended must be minimized and all cost and time estimates must be reliable. This implies that:

a. The length of time the test airplane is commited to the test must be minimized.
b. The number of skilled engineers and technicians necessary to run the test must be minimized.
c. The test usually runs 24 hours/day, until it is complete.
d. Total cost of running the test must be minimized. This cost includes the opportunity cost associated with occupancy time on the test airplane, man

power, equipment and the costs associated with delays in feedback of test results into the airplane development cycle.

2.2 DESCRIPTION OF GROUND VIBRATION TESTING

2.2.1. Definition of Experimental Modal Analysis

Experimental modal analysis is a test procedure for experimentally determining the motion of a structure in response to forces that excite the structure. This description includes a mathematical model for abstracting the behavior of the structure and the values of the parameters in that model. The model chosen is based upon assumptions about the structure's behavior. The values of the parameters are determined by a parameter estimation process applied to measurements of the structure's input (excitation force) and output (motion or response) signals. In this respect the structure is treated as a "black box" problem, in which the behavior is inferred from the input-output measurements. The process of experimental modal analysis generally consists of a measurement phase and an interpretation (or analysis) phase.

2.2.1.1 Measurement

In the measurement phase of a ground vibration test excitation is applied to the airplane and its response is measured. During most ground vibration tests a controlled force input is applied to the airplane and acceleration, velocity or displacement are measured at a number of points on the airplane.

2.2.1.2 Interpretation

Interpretation of the measurements is in terms of the mathematical model assumed for the airplane.

Linear Mathematical Model

A linear mathematical model is usually assumed for the airplane whenever possible. The unknown model parameters interpreted from the test measurements are invariably the modal characteristics of this model; frequency, damping and modeshape. Occasionally additional characteristics are reduced from the measurements. These include generalized mass and point mass, stiffness and damping coefficients.

Non-Linear Mathematical Model

When a linear model is not a sufficient approximation to the airplane's structural dynamic characteristics, a non-linear model must be used. This is done as infrequently as possible, and the models are kept as simple as possible, because this interpretation process is substantially more difficult than in the case of the linear mathematical model. There is no generally applicable nonlinear mathematical model. A model appropriate to the problem at hand must be selected for each application. Considerable research remains to be done on the subject of measurement interpretation for nonlinear mathematical models.

2.2.2 Goals

The identification of the goals of an experimental modal analysis test is an essential part of the choice of best test procedure. At the present time there are three primary uses of modal parameters:

1. Trouble Shooting
2. Modeling
3. Synthesis

Vibration testing is concerned with all three uses of the results at varying points in the life of an airplane. As the use of modal parameters change the test requirements are changed.

In the specific case of the airplane ground vibration test, verification and, if necessary, modification of the mass and stiffness matrices, used in the flutter analysis, is often the primary goal of the test. The construction of a mathematical model for flutter analysis is occasionally the goal, wherein generalized mass, stiffness, damping, and (via the modeshape) aerodynamic force matrices are developed. Modal parameters is a convenient mathematical model which can be applied to both the experimental test and the theoretical analysis.

2.2.3 Assumptions

Three basic assumptions about a structure are made in order to perform an experimental modal analysis which includes a linear mathematical model. First, the structure is assumed to be linear. This means that the response of the structure

to a combination of forces, simultaneously applied, is the sum of the individual responses to each of the forces acting alone (i.e., the superposition principle holds). For a wide variety of structures this is a very good assumption. When a structure is linear, its behavior can be characterized by a controlled-excitation experiment in which the forces applied to the structure have a form convenient for measurement and parameter estimation, rather than being similar to the forces that are actually applied to the structure in its normal environment. For many important kinds of structures, however, the assumption of linearity is not valid. In these cases the linear model that is identified often provides a reasonable approximation of the structure's behavior.

The second basic assumption is that the structure is time-invariant. This means that the parameters that are to be determined are constants. In general, a system which is not time-invariant will have components whose mass, stiffness, or damping depend on factors that are not measured or are not included in the model. If the structure that we are testing is changing with time, then measurements made at the end of the test period would determine a different set of modal parameters than measurements made at the beginning of the test period.

The third basic assumption is that the structure is observable. This means that the input-output measurements that we make contain enough information to generate an adequate behavioral model of the structure. Structures and machines which have loose components, or more generally, which have degrees of freedom of motion that are not measured are not completely observable. Consider describing the motion of a partially-filled tank of liquid when complicated sloshing of the fluid occurs. Sometimes we can make enough measurements so that our system is observable under the form chosen for the mathematical model, and sometimes no amount of measurements will suffice until we change the model.

2.3 STATE OF THE ART REVIEW

2.3.1 Survey

2.3.1.1 Literature Review

The literature reviewed was identified by both manual and automated search procedures. Known articles of value, as well as literature referenced within these articles, were identified first. This material dates back to approximately 1945. Then, independent computer searches were conducted by the University of Cincinnati and The Boeing Company involving the following data sets:

1. NTIS
2. COMPENDEX
3. ISMEC
4. SAE ABSTRACTS
5. NASA
6. DDC
   - Classified
   - Unclassified

The results of the computer searches consisted of about 2,000 listings of title, author, source, and abstract. This computer search process included material no earlier than 1965. Candidate literature items were selected by review of the contents of their abstracts. Finally, the manual and computer searches were combined to eliminate duplication which resulted in approximately 400 pieces of literature being identified. Ninety percent of this literature was acquired.

(See reference lists following this volume.) The most significant literature of the reference material was selected and is summarized in Appendix D by subject matter. A chart summarizing the content of the reviewed literature is shown in Appendix E.

2.3.1.2 Industry Interviews

A series of interviews were held to ascertain the state of the art as practiced in the airframe industry. The groups selected for interview were identified by the Flight Dynamics Laboratory of the Air Force Wright Aeronautical Laboratories as experienced in ground vibration testing. Additional individuals selected as having expertise in vibration testing were also interviewed.

Most of the personal interviews were performed on the site of the organization interviewed. The interviews were conducted by a combined team from the University of Cincinnati and The Boeing Company. Typically, two to three hours were spent in the interview combined with a tour of test facilities and equipment. A standard interview reporting form was used and frankness was encouraged by keeping the details of the interview confidential.

2.3.2 Current State of the Art

2.3.2.1 Airframe Industry Practice

Aircraft industry practice varied widely. All large airframe companies have an in-house ground vibration test group. Their experience levels vary dramatically; some conduct several GVT's a year; others run one test per decade. The

most difficult problem the airframe industry has in conducting vibration testing is in finding, training, and retaining adequately skilled people. A summary of the industry interviews can be found in Appendix C.

The survey disclosed four major reasons why airplane companies conduct GVT:

1. Comparison with a mathematical model developed for flutter analysis
2. Troubleshooting of existing aircraft
3. Research
4. Development of modal parameters to use in analysis

In most airplane GVT's, frequencies, dampings and mode shapes are the desired test result. Where fast Fourier transform equipment is in use, frequency response functions and coherence plots are produced as matter of course. The *more advanced developments*, complex mode shapes, generalized mass, stiffness and damping, transfer functions and orthogonality checks, are less frequently required, although there are organizations where some of these are routine.

Shakers are used for excitation for most airplane ground vibration tests, although occasionally impact and operating inputs are used. Impact testing has been utilized for testing flight control surfaces. Autopilot inputs to a large flight control surface have provided sufficient inertia excitation to shake out critical wing modes on a very large airplane. Single shaker inputs are used to excite both one degree of freedom at a time or multiple degrees of freedom. Of the multiple shaker systems in common use, most are groups of shakers operated in or out of phase to drive symmetric and antisymmetric airplane modes. They are used less frequently in apportioned force approaches. With rare exceptions the

multiple shaker arrangements are used to excite one degree of freedom at a time. Several organizations had research activities addressing the measurement of multiple degrees of freedom using multiple exciters.

The excitation signal used in GVT systems which do not incorporate a fast Fourier transform computer is invariably sinusoidal. The excitation signals generally used with FFT systems are random, although others are used such as sinusoidal, periodic random, random transient, impact, chirp, etc.

The data acquisition techniques used were found to be a function of the GVT development work done. Where little development had been done, a roving accelerometer was used with a strip chart recorder. In the developed systems, over 100 fixed response transducers were used with digitized data being recorded directly on disk under computer control. The norm is a large number of accelerometers with their response recorded directly on analog tape.

Parameter estimation under swept sine and dwell is a single degree of freedom (i.e. a single mode) at a time process. The parameter estimation techniques used with the modal analyzer computers usually used the software provided by the manufacturer. User written parameter estimation algorithms are rarely used on GVT outside research organizations. The algorithms used in GVT are single degree of freedom, single degree of freedom with residuals, multiple degree of freedom, and multiple degree of freedom with residuals.

A free-free support for the airplane in test is universally desired, although there is some disagreement over the frequency separation necessary. Requirements specified varied from 10 to 1 to 2 to 1. At the 10 to 1 end of the spectrum

special aircraft support systems are necessary such as airsprings (XB-70 support system), bungee or mechanical springs. At the 2 to 1 end of the spectrum a bottomed landing gear oleo and soft tires are satisfactory.

It was difficult to always obtain a frank discussion of chronic problem areas. Many of the difficulties expressed seemed to be due to inadequate preparation or lack of skill. As a result, problems were quite often attributed to nonlinearities. The most pressing problem is that the test airplane is available for the GVT for a very short period of time. One of the essential requirements of GVT procedure in the United States is speed. A second problem is that the interface between the test and analysis group is often poor. This is reflected not only in test planning, but in the post-test feedback of data into the analysis group. A third problem is that when introducing new technology, a large pool of acquired knowledge concerning the old techniques is obsoleted, and is only slowly replaced by the familiarity with the new techniques.

Nonlinearities are a chronic problem. Known nonlinearities, e.g., control surface actuator free play, are routinely shimmed or preloaded out, and the airplane is tested as linear. Often a separate test is run to document specific nonlinearities. Unknown nonlinearities often appear during a test. The source of a strong nonlinearity must be determined and fixed before the test may proceed.

Although a pretest analysis is widely regarded as necessary, it usually consists of the free-free modes and frequencies of the airplane mathematical model used in the flutter analysis. On rare occasions it is a forced response calculation predicting the test response of the airplane in GVT configuration, including special modifications of the airplane for test and the airplane support system. The data resulting from the test is used for three purposes:

1. To validate the mathematical model
2. To revise a mathematical model
3. To construct a structural dynamic analysis

In some instances, little or no use was made of the data.

2.3.2.2 Ground Vibration Testing Methods

To compare various methods applicable to experimental modal analysis, a categorization will be used to identify major differences. This section of the report will describe the general characteristics of each method. When discussing criteria for method selection in Section 2.4.1, specific techniques and/or references will be used to evaluate each method.

Ground vibration testing methods are divided into three groups for this evaluation. The first grouping includes all methods pertinent to the forced response analysis technique documented by Lewis and Wrisley. This general testing procedure will be described as a Multiple Point Excitation--Sine Dwell (MPE-SD) approach. The second category that has found widespread application cannot be attributed to any one person or group. It involves measuring frequency response functions and determining modal parameters through comparison to a linear mathematical model. This general testing procedure will be described as a Single Point Excitation--Frequency Response Analysis (SPE-FRA) approach. The final category can best be described as all of the techniques not fitting in the first two general concepts. The reasoning behind this last grouping is that many of these techniques, while showing great promise, do not have adequate

documentation of pertinent details to receive serious consideration as a viable approach at this time. This is not to say that theoretical development is questioned but that little general knowledge of the practical application and results is available at this time. For this reason, most of the discussion under Criteria for Method Selection is limited to the two categories: MPE-SD and SPE-FRA.

Multiple Point Excitation--Sine Dwell Method

Modern MPE-SD techniques are based upon a forced response analysis approach first implemented by Lewis and Wrisley (112) and theoretically developed by Fraejis de Veubeke (45). The basic approach is to apply forces to a structure to compensate for energy loss through damping. If the forces are distributed in proportion to the damping and exactly balance the damping forces, the structure vibrates with the same motion as in the free undamped case.

The primary consideration of any MPE-SD approach is force appropriation. This involves three distinct problems. First, the number of exciters must be sufficient to address the effective number of degrees of freedom. Secondly, the number of exciters should be optimally located to excite a given mode. Finally, the vector forcing function must be determined. Although all three problems are difficult, the first and last can be automated with some success using various methods. The optimum location of the exciters can be evaluated by way of finite element pre-test analysis although no straight forward closed loop approach has been identified.

The use of digital computers has been of great value in the MPE-SD approach. Many of the force appropriation processes have been automated by the use of a

computer controlled system. Data acquisition, storage, and display is more easily handled in a computer based system. Unfortunately, there is no uniform system available commercially that has found widespread use for the MPE-SD techniques. Much of the existing hardware in use has been custom built and ranges up to 15 years in age.

Most MPE-SD techniques involve many similar considerations. All have elaborate excitation control systems (often up to 16 shakers). All depend upon the concept of a phase resonance criteria for identifying the mode. Often Lissajous patterns are used to confirm this. Free decay is normally used to calculate damping factors and to verify the purity of the mode excited. Finally, the diagonalization of the reduced finite element mass matrix is used to verify the orthogonality of the measured modes.

Single Point Excitation--Frequency Response Analysis Method

Present day SPE-FRA techniques are based upon system identification procedures related to a causal black-box concept of structural dynamics. Frequency response functions are analyzed with modal parameter estimation algorithms to determine estimates of modal parameters. Such a process was utilized nearly 20 years ago with equipment known as Transfer Function Analyzers. This process was strictly a swept sinusoidal excitation with tracking filters to determine the output versus input. With the advent of fast Fourier analysis equipment nearly 10 years ago, other forms of excitation, notably broadband frequency signals, allowed complete frequency response functions to be measured in reduced time. The basic approach presently is to excite a structure with an appropriately chosen force signal at one location at a time. The frequency response function between the input force

and output response points of interest are measured and stored. Averaging of a number of inputs and responses is common practice in the development of the frequency response function. Modal parameters are estimated using any of a number of single degree of freedom (SDOF) or multiple degree of freedom (MDOF) algorithms. Often the modal parameter estimation routines take advantage of redundancy in a data set to improve the accuracy of the algorithm.

The primary consideration of any SPE-FRA approach is to obtain the best possible measurement data in the form of a frequency response function. This involves identification of measurement errors, proper location(s) of the single excitation to assure that no modes are missed, and determination of sufficient frequency resolution to identify closely-spaced modes. The use of the coherence function is vital in evaluation of measurement error and averaging requirements.

A secondary consideration of any SPE-FRA approach is to utilize proper modal parameter estimation algorithms. SDOF algorithms are often unacceptable if the modes are closely spaced in frequency. MDOF algorithms often use weighting schemes which provide varying results with the amount of damping present. The current trend is toward a flexible system with a number of SDOF and MDOF algorithms available.

Most SPE-FRA systems are very similar. The hardware is produced by a limited number of manufacturers and is made up of nearly identical components. Certainly the basic measurement capabilities are equal. Software to analyze the data is often available from the manufacturers but no new software systems have been available from this source for three to four years. Often, the individual users program particular algorithms for use on typical structures of a given industry

and much of this software is available from consulting firms, universities, and others. Since all systems are computer based, matrix operations such as orthogonality checks or modal vector manipulations are usually trivial computations to implement.

Other Methods

Two or three approaches are under development which show some degree of promise but for which there is little comprehensive documentation at present. A technique involving broadband multiple point excitation with frequency response analysis is under investigation at the University of Cincinnati. This concept would be very similar to a SPE-FRA approach but without the problems of energy distribution or multiple configurations to assure no modes are missed. A technique based upon free decay and global eigenvalue/eigenvector concepts is under investigation by Ibrahim (87, 88, 89). This system eliminates exciter problems and completely automates the data reduction process. Another new technique under evaluation by Link and Vollan (113) involves direct estimation of reduced mass, stiffness, and damping matrices. This obviously would be of great value in the interaction with finite element models.

For some further details in these areas, the background literature can provide additional information. Little further discussion will be made regarding these methods due to the lack of proven capability. It is of some interest to note, though, that the hardware and general development of the SPE-FRA approach could easily encompass many aspects of these other techniques should any one of them prove to be superior in the future.

2.3.2.3 Specific Techniques Used in Ground Vibration Testing

The state of the art of each of the principal facets of experimental model analysis is described in this section. The various methods of experimental modal analysis use different combinations of these components. These modal analysis methods are discussed in Section 3.1.2.

Excitation Configuration

Excitation configuration refers to the number of simultaneous forces used to excite the structure. Typically, the designation Single Input (SI) or multiple input (MI) is a sufficient description of the situations used for the Multipoint Excitation Sine Dwell (MPE-SD) or Single Point Excitation Frequency Response Analysis (SPE-FRA) techniques. With respect to the two general cases (SI and MI), SI is simple in terms of set-up time and cost of equipment. The inability to distribute energy throughout the structure can cause problems because not all modes can be excited from one point. Because of this, for most airplanes the SI test must be repeated with the excitation at several different locations.

Narrowband (sinusoidal) and broadband frequency excitation with SI can efficiently utilize the fast Fourier transform to develop frequency response information.

MI requires duplication of exciter systems which increases both the set-up time and costs. Additionally, the only practical technique using MI is a sinusoidal, forced response analysis approach. This requires additional control equipment

to achieve force appropriation for a particular eigenvector. If this tuning process is automated (Asher (6, 7) Feix (57), Hallauer (70), Morosow (126, 127), Su (199), Traill-Nash (206)), more sophisticated control equipment is required. No current techniques use broadband frequency excitation with MI. Problems with estimating the number of exciters to use (based upon effective degrees of freedom) and with determining exciter location are difficult. The analysis of eigenvalue and eigenvector is very simple when tuning is successful.

Response Measurement Configuration

Response measurement configuration refers to the transducers used to record the structural motion. The designations of roving set or fixed set describe the configurations commonly used. For the case of a roving set of transducers, equipment is kept to a minimum but time can be a problem if multiple sets of data must be taken. Therefore, this approach is generally unattractive with the MI technique or with SI techniques when multiple configurations of the test structure are required. Calibration and set-up are minimized with a roving set of transducers and the quality of data should be equal to the fixed set of transducers at frequencies below 500 Hertz. As higher frequencies are required, the roving set of transducers must be rigidly attached to the structure. This is normally too time consuming to use.

More equipment is generally required using fixed transducers than roving. Additional time is spent in pre-test calibration and set-up. However, the total occupancy time on the test airplane can be reduced by using more channels of data

acquisition. The amount depends upon the number of points and test configurations. In the case of impact testing, one fixed transducer may be used while the location of the impact excitation is moved. Both multipoint excitation and single point excitation concept can utilize either a roving or fixed set of transducers.

Excitation Signal Format

Excitation signal format refers to the frequency content of the force input(s). The designation of sinusoidal is used to describe signals of only one frequency, while broadband encompasses fast sinusoidal sweeps, transients, and all forms of random signals. Sinusoidal signals have the advantage of minimum information and, thus, an easily recognizable form. This permits time domain analysis in terms of magnitude and phase and is psychologically reassuring during the test phase. Both MPE-SD and SPE-FRA can use sinusoidal excitation although implementation is somewhat different. Normally, with sinusoidal excitation, the input-output relationship is calculated one frequency at a time and modal interaction, particularly in the MPD-SD, is desired to be minimal. This is sometimes not possible to achieve.

Broadband excitation has the advantage of increased frequency content and, therefore, maximum information. The analysis of such data requires digital signal processing techniques such as fast Fourier transforms, digital filtering, and averaging to obtain frequency response information. Thorough understanding of the mathematics and peculiar physical phenomena (aliasing, leakage, etc.) of digital signal processing are required. Modal interaction is not suppressed by the excitation.

Confidence Factors

There are several confidence factors applicable to measurement. The first is repeatability. This involves duplicate measurements using the same procedures or measurements taken via different procedures. A second measure is to compute the coherence function. Holes in the coherence function immediately flag deficiencies in the measurement, local modes, or extraneous inputs to the system such as noise or non-linearities. The third measure is decay trace frequency and amplitude stability and logarithmic amplitude linearity. Deviations will indicate inadequate tuning, poor signal-to-noise ratios, nonlinearity and other problems.

Data Acquisition

The measurement process may involve testing many configuration variations. In a sinusoidal technique, data acquisition requirements dictate single word storage for the input and output measurements at each identified frequency. In wideband techniques, much more computer memory is required since many frequencies are processed simultaneously. Both situations can achieve an improvement in accuracy through averaging.

Filtering equipment is normally involved in most techniques whether for purposes of elimination of aliasing, narrow-band tracking, or reduction of noise. Care must be taken in applying filtering techniques to avoid any compromise or degradation of the data due to the unique problems associated with filters, e.g., rolloff, truncation.

Transducer sensitivity and amplifier characteristics need to match the other test equipment so that maximum accuracy can be maintained.

Sufficient time must be spent during the measurement phase to ascertain both the validity and quality of the data. This involves averaging where necessary as well as the use of coherence function. Even small errors or compensations made during this phase increase the potential difficulty in estimating the modal parameters.

Interpretation of Measurement

The current techniques of modal parameter estimation may be categorized as modal parameter estimation via direct measurement and modal parameter estimation via frequency response analysis. In the direct measurement technique the test apparatus is adjusted so that, in the judgement of the operator, the test item is vibrating in a normal mode. The frequency of vibration is recorded as the natural frequency and the displacement amplitudes are recorded as modeshapes. In the frequency response analysis technique, frequency response functions are developed from the measurement. A frequency response function can be developed by a slow sine sweep at constant input force amplitude, in which case the frequency response function is the displacement as a function of frequency. More commonly the frequency response function is developed by Fourier transforming time histories of the input force and the resulting displacement. Note that a frequency response function refers to the response of the structure at one point to excitation at another, and that a set of frequency response functions is necessary to describe the dynamic characteristics of the entire test item.

In addition to modal parameter estimation by direct measurement and by frequency response function analysis, there are several hybrid techniques that combine features of both approaches.

Characteristics of Modal Parameter Estimation

Single Degree of Freedom - Modal parameter estimation techniques which involve *only one eigenvalue and* eigenvector at a time are classed as single degree of freedom (SDOF) techniques. The oldest method is attributed to Kennedy and Pancu (96) and is often referred to as the "circle-fit" method. Using the amplitude and phase at the damped natural frequency or the quadrature part of the frequency response at the damped natural frequency are common techniques (Broadbent (23), Brown, (222), Klosterman(99)). More sophistication is gained by using a single partial fraction expansion, in the area of the damped natural frequency, based upon the Laplace domain formulation for a SDOF with damping (Stahle (194, 195), Richardson (169, 170), Sloane (187)).

SDOF techniques are simple to implement and analysis time is kept to a minimum. The amplitude and quadrature techniques are essentially those used in MPE-SD techniques. Little operator skill or interaction is required, however, closely spaced eigenvectors and coupled eigenvectors can be very difficult to separate with SDOF techniques.

Multiple Degree of Freedom - Multiple degree of freedom (MDOF) techniques are more complicated in terms of time operator skill, and operator interaction. Such techniques are usually based upon non-linear solution procedures of a partial

fraction expansion of the Laplace domain formulation of the mathematical model. Often matrix procedures are used to take advantage of special forms of the data. These processes can be very slow since one frequency response function is analyzed at a time. In addition, the current techniques do not take advantage of redundant information (global eigenvalues or eigenvectors). This is the subject of much current research and considerable improvement may be anticipated in the future.

The operator skill is imperative in current MDOF techniques. The evaluation of "goodness of fit" is not always obvious nor is the specific choice of the number of degrees of freedom. These two considerations alone can mean the difference between satisfactory and meaningless results. Additionally, the time required by the operator to manually manipulate these factors causes the total time for analysis to increase. Therefore, those MDOF techniques which can give better results through automatic procedures are very attractive.

Complex Eigenvectors - Complex eigenvectors is the general characteristic found in real structures, with real eigenvectors being a special case which occurs with proportional damping. The MPE-SD techniques do not permit the formulation of complex eigenvectors and, thus, the results are always real eigenvectors. The SPE-FRA techniques allow complex or real eigenvectors depending upon the mathematical model chosen. Currently, the mathematical model methods commonly used to approximate the test configuration, due to time constraint, cost and experience, are real eigenvector solutions. In the aerospace industry, the structures are

often satisfactorily evaluated based upon real eigenvectors alone. When problems are encountered in force appropriation with MPE-SD techniques, the complication is attributed to poor exciter locations, insufficient number of exciters, or inadequate iteration in the tuning. The existence of complex eigenvectors may often be an additional significant source of difficulty.

Residuals - Both SDOF and MDOF techniques may or may not involve the use of residuals. Residuals are variables which are used to approximate the effects of eigenvectors below and above the frequency range of the modal parameter estimation technique. The constant associated with the lower eigenvectors is often referred to as inertia restraint and the constant associated with the higher eigenvalues is called residual flexibility. Some techniques do not allow the use of residuals (for example quadrature) but most of the sophisticated SDOF and MDOF techniques permit them. Residuals are necessary in the separation of modal interaction to accurately credit the proper influence to each mode.

Global Eigenvalue - Global eigenvalue refers to the concept that the eigenvalues are constants with respect to the test structure. If this contraint is imposed in the MDOF estimation techniques, the solution process can now be linearized. This has the benefit of reduced operator interaction, simplification of analysis, and overall improvement of eigenvalue estimate. Obviously, a side benefit is a great reduction in analysis time (Brown (222), Ibrahim (87, 88)). Some difficulty can be encountered if measurement errors or non-linearities are present, since the eigenvalues will then appear to change between measurements.

Global Eigenvector - Global eigenvector refers to the concept that the major structural modes of vibration should be observed to be unchanged regardless of where the test excitation is applied to the structure. Therefore, if multiple applications of a single point excitation can be separately analyzed and combined or collectively analyzed, the result should be a single eigenvector for each eigenvalue. Manipulation of estimates of eigenvectors from different test points can give improved definition of a global eigenvector as well as statistical input as to the variance in the measurements. Work relating to this concept has been formulated by Ibrahim (87, 88) and Richardson (172).

Local Eigenvectors - In addition to global eigenvectors, the ability to allow local eigenvalues and eigenvectors is very important. Measurements in a certain area of the test structure may contain modal parameters which are not found over the rest of the structure. If the modal parameter estimation techniques cannot permit additional degrees of freedom when this situation exists, the estimated values for the global eigenvectors will be very poor.

The capability to handle local modal parameters as well as global modal parameters requires increased refinement in the software. This will permit more automation and less operator interaction. Current applications of such techniques have been very time consuming because they are based upon non-linear solution methods. The application of linearizing techniques to the solution as well as increased automation may provide a great reduction in analysis time.

Confidence Factors - The confidence factors for use in modal parameter estimation are less well developed than those for use in measurement. They detect poor quality but do not ensure high quality.

A first check is to compute the generalized mass matrix from the estimated mode shape and a "given" point mass model of the test item. A general rule of thumb requires the off diagonal terms be no more than 10 percent of the diagonal for an acceptable mode. A second check is to compare modal parameters predicted in a pretest analysis to those estimated from test. Since error metrics have not been developed for use in this area, the basis for comparison is intuitive. A third commonly used check is to predict the system response using the estimated parameters. This is done most effectively in the time domain by predicting the system response to a known arbitrary forcing function and comparing the measured response to this forcing function. One may also predict frequency domain response, although this is less useful.

2.4 SELECTION OF RECOMMENDED GVT METHOD

2.4.1 Criteria For Method Selection

This section contains the key points in the evaluation process. The criteria for evaluation were developed from the contract Statement of Work, industry interviews, and personal experience. The weighting of the criteria is based upon identifying the optimum GVT technique within the restriction of well-documented, state of the art practice. Those criteria which rate purely mechanical considerations and apply to most or all techniques equally have been given very little weight. The evaluation of the general methods with respect to the criteria is based upon a review involving literature, industry interviews, and personal experience. This evaluation did not seriously consider many pieces of literature which lacked a sufficient documentation of detail, a sufficient demonstration of proficiency, and/or an adequate evaluation of real world examples.

2.4.1.1 Primary Considerations

The following criteria are basic concerns in the evaluation of any GVT approach. The subtopics are in order of decreasing importance in method selection.

Quality of Results

The MPE-SD approach and the SPE-FRA approach appear to be nearly equal in the ability to obtain modal parameters for a given structure. Of the other techniques, insufficient documentation is presently available, although the Link and Vollan (113) and Ibrahim (88) approaches show future potential. For aircraft structures, the MPE-SD approach may be slightly superior but the continuing availability of improved modal parameter estimation algorithms for the SPE-FRA method indicates that any small advantage is temporary.

Time Constraint

The amount of time needed to complete a GVT is in direct conflict with the need for quality of modal parameter estimates. Any reduction in available test time due to impending flight schedules or previous delays contributes directly to the degradation of the final result. None the less, the high cost of hardware, test fixturing, and personnel dictates that total test time be kept to a minimum.

The MPE-SD approach appears to give superior results for a reduced number of modes if the time constraint is severe. Since each mode is tuned independently, not all modes will be documented and potentially important modes will be missed.

This is a direct result of the variability of the amount of time needed to tune a given mode. The requirement of individual tuning of modes does not permit any separation of tasks (which would permit some of the analysis to be performed at a later time).

When the time constraint is severe, the SPE-FRA approach will yield some data on all or nearly all modes of interest. Also, based upon an exact time constraint, a reliable estimate of the maximum amount of data to be acquired can be made. This assures, assuming confidence factors are utilized, that some information about all modes can be obtained. This ability to spend the total test time window in the measurement process, if needed, while deferring the time consuming analysis phase represents a unique and powerful attribute of the SPE-FRA approach.

When time constraints are completely removed, both approaches yield similar results. There is a tendency for the MPE-SD technique to obtain fewer modes even though the global modes are found. An example of this can be seen in a recent paper by Hanks, et all., (75).

Operator Expertise

Both the MPE-SD and SPE-FRA approaches, with respect to the present state of the art, require a very high level of operator expertise. Through industry interviews and literature discussions, it is obvious that this requirement is often overlooked. The aircraft design that requires experienced finite element engineers for the analytical solution often is left to completely inexperienced

technicians and engineers for the experimental solution. This is a management problem that needs to be corrected.

The MPE-SD approach is at a slight disadvantage since the operator expertise is involved in tuning each mode. The primary involvement of operator expertise in the SPE-FRA approach is in the modal parameter estimation phase. In both approaches a knowledgeable test engineer is required to continuously evaluate the measurement process.

A very popular misconception of the SPE-FRA approach relates to the concept of operator expertise. An expert operator who is estimating modal parameters using various SDOF and MDOF algorithms cannot compensate for poor data (noise, aliasing, leakage, distortion, frequency resolution, etc.). These software routines cannot efficiently extract reasonable modal parameter estimates if the data was taken carelessly. This accounts for far more of the failures of the SPE-FRA approach than is generally recognized.

Within the limitations summarized, both the MPE-SD and the SPE-FRA approaches involve a similar degree of operator expertise and experience. Again, with future developments, the availability of better, faster, and more automatic modal parameter estimation algorithms will give the SPE-FRA approach an advantage.

Closely Spaced Modes

Closely spaced modes create equal problems in all techniques. The MPE-SD approach requires more tuning in force appropriation. The SPE-FRA approach requires more interaction in the modal parameter estimation process. These factors in terms of difficulty are judged to be essentially equal. The more significant result of closely spaced modes is an increase in time to achieve equivalent estimates of modal parameters.

Increased Accuracy

Since both the MPE-SD and SPE-FRA approaches currently result in similar quality of results, the question of increased accuracy is dependent upon identification and solution of the problem areas within each technique. To improve the MPE-SD technique, the number of forces, the force location, and the force appropriation must each be automated. Limited success has been achieved in determining the number of forces and the force appropriation with automated procedures. No documented effort has been made to determine optimum force location. An unfortunate problem with the development of the MPE-SD approach is that only those individuals interested in improving GVT techniques are contributing to the improved procedures; there is no cross-furtilization of MPE-SD improvements from other areas of technology. To improve the SPE-FRA technique, measurement technique and modal parameter estimation algorithms must be improved. Great success in both areas has taken place over the last ten years and is continuing. The distinct advantage in the development of the SPE-FRA approach is that these areas are of great interest to researchers in other areas such as controls and electronics. A reasonable amount of technology transfer can be expected.

Many of the theoretical studies performed to analyze the accuracy of either method have proven to be less useful than anticipated. Most examples have utilized an MDOF model with random noise to use in a comparative study. In the real test environment, the noise due to extraneous inputs and measurement error is rarely white random and almost always biased. Studies based upon white random noise are not necessarily appropriate measures of the ability to accurately estimate modal parameters.

Complex Modal Coefficients

The question of real versus complex modes must be considered in terms of the quality of the experimental modal analysis approach. The MPE-SD approach does not lend itself to the concept of complex modes. All other approaches, including SPE-FRA, can utilize real and complex mode concepts.

There is no doubt that much GVT work can be satisfactorily accomplished without the complex mode concept. The real world though does have complex modes and in order to accurately describe the phenomena measured, this capability is required both analytically and experimentally. Some flexibility in the definition of phase resonance and in the definition of orthogonality of modes is often taken with the MPE-SD approach. This flexibility may be necessary to compensate for the inability of the MPE-SD approach to deal with slightly complex modes. The MPE-SD approach does not contain the flexibility to document this realistic possibility.

Complicating Factors

Most complicating factors in the GVT process are related to some nonlinear characteristic in the test item. Neither MPE-SD nor SPE-FRA approaches are ideally designed to address this kind of difficulty. Both approaches can handle such a complicating factor as a nonlinearity with equal effort and success. If the mathematical form of the nonlinearity is known a priori, the SPE-FRA would have a distinct advantage.

Confidence Factors

Recognition of good or poor estimates of modal parameters during the test window is vital to the resulting quality of the GVT. The two basic approaches each contain methods for on-line determination of confidence prior to completion of the total test protocol. Using the MPE-SD approach, the ability to approach the phase resonance criterion at all shakers for a given mode can be very useful. Unfortunately, if too few inputs are utilized this result may be misleading. The decay of the mode of vibration when the inputs are removed is another potential measure of the purity of the single mode excited by the MPE-SD approach. This is very useful in concept, but when a small amount of distortion is present, the question of 'how much is too much' is not always easy to answer. Additionally, the MPE-SD approach can involve mode orthogonalization as a measure of confidence after each mode has been tuned.

The SPE-FRA approaches have useful confidence factors as well. The coherence function calculation associated with each frequency response function gives a

good indication of the amounts of noise, sensitivity problems, and measurement error such as leakage. Unfortunately, since this function is a frequency dependent quantity between zero and one, the question of 'how bad is too bad' must be answered. Additionally, any lack of experience and knowledge in using the coherence function in this manner provides some difficulty. The ability to estimate modal parameters quickly using SDOF techniques allows partial mode shapes to be processed during the test to check consistency of data or problems with closely spaced or coupled modes. The use of many separate input locations and increased frequency resolution during an initialization stage also results in on-line alteration of test protocol to assure that no modal information is missed. Other techniques, such as mode orthogonalization, can be involved in the on-line confidence factor process but realistically lend themselves to post-processing confidence considerations.

In summary, both the MPE-SD and the SPE-FRA approaches have adequate confidence factors available. The confidence factors available presently are of approximately equal merit but the SPE-FRA approaches require proper background education. The ability to involve averaging in the measurement and analysis phases of the SPE-FRA approach allow for application of statistics in the confidence building process.

2.4.1.2 Secondary Considerations

Some of the criteria involved in method selection need to be considered but are not primary considerations. Four subtopics have been identified within this weighting category. The first two subtopics are important but should be sacrificed to maintain the integrity of the primary considerations. The final two subtopics are also important but apply somewhat equally to the MPE-SD and SPE-FRA approaches. Once again each succeeding subtopic is in order of decreasing importance in method selection.

Cost Reduction

The total cost of a GVT is an important concern. With both the MPE-SD and the SPE-FRA approaches, the test hardware represents a trivial cost compared to the total test cost. It is remarkable, though, that despite this fact, there is some reluctance to provide more hardware to facilitate parallel processing and computer controlled data handling. The significant cost is normally the involvement of the test airplane, fixturing, and personnel during the total test time window. The ability to process more data faster significantly reduces total test cost for very little expenditure. Therefore, the time constraint directly determines the cost factor. Both the MPE-SD and the SPE-FRA approaches can be optimized in terms of parallel data processing and handling in similar ways.

One significant advantage of the SPE-FRA approach with respect to cost reduction is the ability to defer some or all of the analysis to a later time. In this way the test configuration need only be maintained during the measurement phase.

Only the equipment and personnel involved in the estimation of modal parameters need to be budgeted for the total time period.

Personnel Reduction

At the present state of the art, neither the MPE-SD approach nor the SPE-FRA approach can account for significant personnel reduction. Both testing concepts can be run with minimum personnel involvement if time is not critical. Likewise, both testing concepts benefit during test set-up and data measurement by parallel tasking of technician level support. Since exciter and transducer set-up is labor intensive, the SPE-FRA approach maintains a small advantage due to a reduction in the number of exciters utilized.

Application to Sub-Assemblies

Any experimental modal analysis technique used for GVT purposes is capable of testing subassemblies of the complete aircraft structure. Typical examples of such components would be the landing gear, nacelle mounted engines, control surfaces, stores or a scaled flutter model. The MPE-SD and SPE-FRA approaches can both be used for such purposes. Since the SPE-FRA only requires a single excitation and can be used with techniques such as impact testing, the flexibility of this technique is a distinct advantage when cost, time, personnel and/or test fixturing problems would mitigate against the use of the MPE-SD approach.

Post-Test Analysis

The ability of a GVT method to provide input to computational schemes for comparing and checking experimental results with analytical prediction is another valuable criterion. The calculation of generalized mass or the use of a reduced finite element mass matrix to check mode orthogonality are common examples of this need. Since the MPE-SD and the SPE-FRA approaches both normally involve a direct interface to at least a mini-computer, such calculations can be attempted with either approach quite easily. The frequency response functions utilized in the SPE-FRA approach result in a larger available data base. The concepts of modal synthesis, time domain simulation, frequency response and loads prediction are all currently under development and may require a large data base to obtain accurate results. As these methods are developed to the point of routine application, the SPE-FRA approach appears to be more capable of providing the data base that will be required.

2.4.1.3 Minor Considerations

The remaining criteria to be considered are of equal merit in both techniques and cannot be heavily weighted for purposes of the selection of an optimum GVT method.

Input/Output Format

The ability to present modal data in a variety of formats is extremely useful. The data may need to be on punched cards or magnetic tape for further analysis. Modal shapes should be animated for visual perception as well as CRT and hard

copy plots with appropriate annotation for report purposes. There is no difference in capability of such presentation of the modal data in any of the experimental modal analysis techniques.

Hardware Portability

Both the MPE-SD approach and the SPE-FRA approach are portable enough to provide GVT capability. Any such system required can be placed in a large trailer and moved to a remote site if necessary.

Safety

The safety of personnel involved with the test as well as the test airplane is of vital concern always. No significant difference exists in the application of any method discussed.

2.4.1.4 *Summary*

The comparison of the MPE-SD and SPE-FRA methods is summarized in Figure 1. Based on this evaluation, the SPE-FRA method is recommended as the better method. The elements of the method are discussed in detail in Section 3.0.

The SPE-FRA method is selected as the method for further development when considering both the primary and secondary weighted criteria. Consideration of minor criteria shows neither method at advantage. Although the MPE-SD and the SPE-FRA approach appear to be nearly equal in ability to obtain modal parameters

Criteria	MPE-SD	SPE-FRA
Primary		
Quality of results		
Complex modal coefficients	-	+
Closely spaced modes	+	+
Complicating factors	+	+
Confidence factors	+	-
Increased accuracy	-	+
Time constraint	-	+
Operator expertise	+	+
	—	+
Secondary		
Cost reduction	-	+
Personnel reduction	+	+
Subassemblies	-	+
Post-test analysis	-	+
	—	+
Minor		
I/O format	+	+
Portability	+	+
Safety	+	+
	+	+
Summary	—	+

Figure 1. Method Selection Summary

of a structure, the continuing availability of improved modal parameter estimation algorithms for the SPE-FRA method is a decided advantage. The consideration of complex modal coefficients, closely spaced modes, complicating factors, confidence factors and increased accuracy lead to a decision in favor of SPE-FRA. The other primary criteria, the time constraint and operator expertise both favor SPE-FRA. Consideration of secondary criteria, cost reduction, personnel reduction, treatment of sub-assemblies and post test analysis also support a decision in favor of the SPE-FRA method.

2.4.2 Analytical Studies of the Modal Estimation Process

Part of the work for the method selection process was to conduct simple computer evaluations of the potential methods. In the evaluation of the literature, there were a number of computer studies of both the multi-point excitation and the single point excitation methods: Craig and Su (34), Feix (57), Asher (6), Berman and Flannelly (14), Sloane and McKeever (187) and Gold and Hallauer (223). Instead of duplicating these studies in a similar fashion, the literature was reviewed.

The computer simulations conducted were limited to evaluation of the parameter estimation schemes that will be used during the contract. Studies were made upon the sources of errors in making frequency response measurements and the sources of errors in the evaluation of curve fitting algorithms which are used for the parameter estimation phase of the GVT (see Section 3.1). It should be noted that one of the problems noted in the literature and in our own computer studies is that an ideal system is normally simulated and then its characteristics are

computed using the algorithm to be evaluated. Most of the algorithms that are evaluated in this fashion work well since in most cases noise added to the process to simulate the noise involved in the measurement processes is Gaussian distributed. Most of the curve fitting process work well on this type of data. Unfortunately, the type of noise that is common to an actual measurement process has large bias errors due to nonlinearities or other excitation sources which may exist in the testing environment. As a result, these techniques which often appear to work well in the computer studies do not work well in practice.

In the literature there were a number of studies where the multiple point method was evaluated against single point random or some other method. It was clearly evident from these studies that in most cases the testing group was expert with one technique but lacked experience with the other techniques. As a result, the evaluation was clearly biased towards the method they were expert in. Another problem was that a piece of hardware was tested whose exact characteristics were unknown. The test structure was normally complicated. There were questions concerning the validity of the existing finite element model. As a result, it was difficult to determine just how well each technique performed.

3.0 RESULTS

3.1 *RECOMMENDED GROUND VIBRATION TESTING METHOD*

The method which is recommended for ground vibration testing of aircraft is the single point excitation/frequency response analysis method. The reasons for the selection of this method are given in the previous section.

In this section the method that has been selected will be described in detail. The implementation of the method is described in Appendix A, "Guide for Ground Vibration Testing of Airplanes". Note that one of the main reasons for choosing this technique is because it will be expanded by future research to include much better parameter estimation schemes. When these are developed they will replace some of the techniques which will be described in this section.

In this section the excitation procedures, measurement procedures and data analysis method will be described. Also, measurement equipment and data analysis equipment will be discussed.

3.1.1 Measurement Phase

In using this method it is necessary to measure the frequency response between a number of exciter positions (force input points) and a number of output points (displacements). The frequency response measurements can then be used to estimate the modal parameters of the aircraft and/or aircraft system. Different exciter locations are used to estimate different sets of modal parameters. The

number of exciter positions depends upon the nature of the GVT and the complexity and modal density of the aircraft system. The frequency response measurements can be made several different ways. The preferred technique is determined by a number of factors:

1. The type of measuring equipment and the number of simultaneous input channels,

2. The characteristics of the structure (linear or nonlinear),

3. The testing environment,

4. The test time window, and

5. The purpose and type of GVT (total aircraft, control surface, etc.).

The type of equipment used, analog or digital, is important. It is recommended that a digital system be employed because it has the greatest flexibility in the measurement phase and can also be used to reduce the data. The analog method is very slow since it is limited to swept sine testing unless a large number of multiple channels of data are processed simultaneously.

With the digital equipment, periodic, random, transient and operating inputs can be used to measure the frequency response. Also, the digital system can be updated periodically by simply updating the measurement and data analysis software. As mentioned in the previous section, there is a great amount of research

being conducted by a number of researchers in the area of structural system identification and these improved techniques can be incorporated into a digital system.

If the system is linear then any excitation technique can be used to measure the frequency response of the aircraft. However, for nonlinear structures it is important to use a measurement technique which will generate a frequency response measurement which is compatible with the selected parameter estimation scheme. In the following sections, the frequency response measurement and parameter estimation schemes will be described in detail.

3.1.1.1 Excitation Techniques

The excitation techniques can be classified into four general categories; periodic, random, transient and operating.

A periodic signal is one which repeats itself with a given time interval or varies in a manner which is slow enough that in terms of signal processing it can be considered periodic. Examples of this type of input are swept sine, pseudo random and periodic chirps.

A random input signal is a non-deterministic signal which can be characterized by a probability density function and a power spectral density function. This kind of input can be pure random or periodic random, where periodic random is a cross between pure random and pseudo-random.

A transient signal is one where the excitation force changes drastically as a function of time but changes in a deterministic fashion. In most cases the input force decays to a steady state value after a short period of time. Examples of transient inputs are impulses, unit steps and chirps (fast sine sweeps).

The operating input corresponds to input forces generated by the actual device being tested.

Periodic Signals

Swept Sine Testing - Since swept sine testing has been in use since the early 1960's it is the most popular and best understood of the excitation methods. The procedure used is a simple one. A sweep oscillator is used both as an input to an electro-mechanical or hydraulic exciter and as the tuning signal to a narrow band tracking filter. The frequency sweep rate is sufficiently low that the excitation and response are very nearly sinusoidal. The force input to the system is measured with a load cell and the response of the system is measured with a suitable transducer such as an accelerometer or velocity pickup. The signals from the transducers are passed through the tracking filters to log converters where signals proportional to the logarithm of the force and response are produced.

The logarithm of the force signal is subtracted from the logarithm of the response signal yielding a signal proportional to the log of response divided by force. The two signals are also passed through a phase meter to get the relative

phase between the force and response. The output of this type of system typically goes to an X,Y,Z plotter where it is plotted as amplitude and phase versus frequency. The output could also be digitized and fed into a digital computer for further analysis. By sweeping the oscillator through the entire frequency range of interest, the frequency response can be generated.

The principal advantage of swept sine testing is that the input force can be precisely controlled. This is particularly useful in the study of nonlinear systems. By measuring the frequency response of the system with several different force levels, much can be learned about the cause and behavior of the nonlinearity. Because all signals at frequencies other than the input frequency are filtered out, swept sine testing gives the best signal to noise ratio at the measurement frequency of any of the excitation techniques. Swept sine testing also has the advantage that it can be performed with relatively inexpensive analog or digital equipment.

The major disadvantage of swept sine testing is that it is slow. A test of the frequency range from 1 Hz to 100 Hz with a two Hz bandwidth filter takes approximately 20 minutes. Another disadvantage of swept sine testing is that it gives a very poor linear approximation of a nonlinear system. This is a serious problem if the data is to be curve fitted to estimate modal parameters since digital parameter estimation schemes are all based on linear models and the premise that the structure behaves in a linear manner.

The advantages of swept sine testing are:

1. It has the best peak to rms energy ratio;

2. It has, by far, one of the best signal to noise characteristics;

3. It is good for documenting the nonlinear characteristics of the test system;

4. It has the longest history of use and as a result it is the most widely accepted input.

Its disadvantages are:

1. For nonlinear systems the measurement doesn't have the form that satisfies the curve fitting models used to obtain the modal coefficients.

2. It is slow. It will take at least 20 minutes for a measurement in the 0-100 Hz range. For a typical modal survey conducted on an aircraft a total of more than a thousand frequency response measurement may be taken. This would correspond to several months of work. With the other techniques the test could be done in several days.

Pseudo-Random - Because of the development of the digital Fourier analyzer, pseudo-random input testing has become a practical method of frequency response measurement. Using Fourier transforms it is not necessary for periodic inputs to be sinusoidal; they can have almost any spectrum content. In fact it would be

possible, though not practical, to tune a large number of oscillators to different frequencies, mix the signals together and use the resulting signal to excite a system. In one sample of data it would be possible to determine the frequency response of the system at all the excitation frequencies.

In practice the procedure for implementing a pseudo-random signal is to use a digital to analog converter (DAC) connected to the computer of the Fourier analyzer to generate the excitation signal. The signal is created in the frequency domain, normally with uniform amplitude and random phase angle throughout the desired frequency range. If necessary, the amplitude versus frequency characteristics of the signal can be modified to compensate for impedance mismatch between the exciter and the structure thereby producing a flat shaker output spectrum. Once the desired frequency domain signal is produced, it is Fourier transformed into the time domain and output to the exciter system through the DAC. This process leads to one of the important advantages of pseudo-random excitation. Because the excitation signal is created in the frequency domain and transformed into the time domain, it is always periodic within the sample window and therefore does not suffer from the leakage errors of the pure random signal. Because the signal contains energy at all frequencies of interest, it is possible, in a low noise environment, to make a reasonably good frequency response measurement with only one sample of data. In normal testing environments, a few samples may be required. One of the principle disadvantages of pseudo-random excitation is that nonlinearities or loose components will generate periodic noise which cannot be averaged out of the data. Due to this condition, the overall quality of a pseudo-random measurement is generally lower than that made by any of the other techniques. However, in mode shape surveys, where several

hundred measurements may be made with no intention of curve fitting for frequency and damping, the speed of pseudo-random is a fair tradeoff for lower quality data.

For linear systems in low noise environments, pseudo-random is a good choice for modal surveys. A structure for which it would work well would be a frame type structure. A structure for which it would not work as well would be an aileron system because of the nonlinearities in the flight control system.

The advantages of pseudo-random are:

1. It is fast. For a frequency range of 0 to 100 Hz it takes one sample period of the Fourier analyzer to produce the frequency response. This is about 6 seconds for 1024 time domain points. This compares to about 20 minutes for a similar test using swept sine excitation.

2. It is controlled. Both the amplitude and frequency content of the excitation signal can be precisely controlled.

3. It has a low ratio of peak to rms energy.

4. Noncoherent noise can be conveniently averaged out.

5. Leakage errors are eliminated by using an input that is periodic within the sample window of the Fourier analyzer.

Its disadvantages are:

1. It is very sensitive to rattles. Loose components generate periodic coherent noise which cannot be averaged out. The noise appears as spikes on the frequency response measurement which can cause difficulty in curve fitting the data to extract modal parameters.

2. The energy input at any given frequency is small compared to swept sine. The reason, of course, is that all frequencies are being excited simultaneously.

Periodic Fast Sine Sweep - Another choice of a periodic time domain signal is the periodic fast sine sweep. Good test results are obtained using the periodic log swept sine forcing function by actually making the function a true transient signal. The log swept sine forcing function is formed by means of software in a Fourier data block and output through the DAC to the exciter. Since timing is critical in making a truly periodic forcing function in the Fourier analyzer's sample time (T), a transient signal is sometimes used that allows time for the response to die out before the end of the time sample T. This is accomplished by stopping the sweep typically at 85% of the total time sample taken. The modal damping values of the system under test will dictate this length. Lightly damped systems may require stopping the sweep at 70%. In any event, the sweep is stopped, allowing enough time for the systems to decay out to 10% or less of its peak resonnance. To soften startup and shutdown transients, the amplitude of the sweep time history are also linearly ramped using a 5% ramp time at the beginning and the end of the sweep.

In the measurement phase of the test, the swept sine has an appealing nature compared to random in that as each resonance is traversed the response blossoms, giving a quick intuative feel as to signal-to-noise ratios and system dampings. Data dropouts and other anomalies are much easier to recognize using sine versus random. The periodic sine sweep gives good signal-to-noise ratios and good peak to RMS energy ratios. Leakage errors are eliminated by virtue of its periodicity. Its main disadvantage is that any nonlinearities are not averaged out. In a ground vibration test of a complete aircraft, the small nonlinearities within the structure can present a serious problem when attempting to curve fit the data to obtain modal parameters.(93)

Random Signals

Pure Random - Pure random excitation typically has a Gaussian distribution and is characterized by the fact that it is in no way periodic, i.e., it does not repeat. The output of a random signal generator may be passed through a bandpass filter to concentrate energy in the band of interest. Generally the filter spectrum will be flat except for the filter rolloff and, hence, only the overall level is easily controlled.

One disadvantage of this approach is that, although the shaker is being driven by a flat spectrum, the structure is being excited by a force with a different spectrum due to the impedance mismatch between the structure and the exciter. This means that the force spectrum is not easily controlled and the structure is not being excited in the optimum manner. Since it is difficult to shape the spectrum because it is not generally controlled by the computer, some form of closed loop force control system would ideally be used.

A more serious problem of pure random excitation is that the measured input and response signals are not periodic in the measurement time window of the Fourier analyzer. A key assumption of digital Fourier analysis is that the time waveforms be exactly periodic in the observation window. If this condition is not met, the corresponding frequency spectrum will contain "leakage" due to the nature of the discrete Fourier transform; that is energy from the nonperiodic parts of the spectrum will "leak" into the periodic parts of the spectrum, thus giving less accurate results (161).

In digital signal analyzers, nonperiodic time domain data is typically multiplied by a weighting function, such as a Hanning window, to help reduce the leakage caused by nonperiodic data and a rectangular window. When a nonperiodic time waveform is multiplied by this window, the values of the signal in the measurement window more closely satisfy the requirements of a periodic signal. The result is that the leakage in the spectrum of a signal that has been multiplied by a Hanning window is reduced.

However, multiplication of two time waveforms, i.e., the nonperiodic signal and the Hanning window, is equivalent to the convolution of their respective Fourier transforms (recall that multiplication in one domain is exactly equivalent to convolution in the other domain). Hence, although multiplication of a nonperiodic signal by a Hanning function reduces leakage, the spectrum of the signal is still distorted due to the convolution with the Fourier transform of the Hanning window.

With a pure random signal, each sampled record of data T seconds long is different from every other sample. This gives rise to the single most important advantage of pure random excitation. Successive records of frequency domain data can be ensemble averaged together to remove nonlinear effect, noise, and distortion from the measurement. As more and more averages are taken, all of these components of a structure's motion will average toward an expected value of zero in the frequency domain data. Thus, a much better measure of the least squares estimate of the structural response can be obtained. This is especially important because digital parameter estimation schemes are all based on linear models and measurements that contain distortion are more difficult to fit.

The advantages of pure random are:

1. It gives the best linear approximation of a nonlinear system.

2. It is relatively fast. It is slower than impact or pseudo-random but is significantly faster than swept sine.

3. It is well controlled. The force levels can be easily and accurately controlled.

4. It has good peak to rms values.

The disadvantages of pure random are:

1. For lightly damped systems, the frequency resolution of the discrete Fourier transform can be a serious problem. However, this problem can be reduced or eliminated by using a zoom transform.

2. It is difficult to control the frequency spectrum without using special computer software and hardware.

3. Serious leakage errors exist because pure random excitation is not periodic in the Fourier Analyzer time window.

Periodic Random - Periodic random input combines the best features of pure random and pseudo-random, but without the disadvantages, that is, it satisfies the conditions for a periodic signal, yet changes with time so that it excites the structure in a purely random manner.

The process begins by outputting a pseudo-random signal from the DAC to the exciter. After the transient part of the response has died out and the structure is vibrating in a steady state condition, a measurement is taken, i.e., the auto and cross spectrums are formed. Then, instead of continuing to output the same signal again as in pseudo-random excitation, a different uncorrelated pseudo-random signal is synthesized and output. This new signal excites the structure in a new steady manner and a new measurement is made.

When the power spectrum of many measurements are averaged together, nonlinearities and d stortion components are removed from the frequency response measurement. Thus, the ability to use a periodic random signal eliminates leakage problems and ensemble averaging is now useful for removing distortion because the structure is subjected to a different excitation before each measurement.

The only drawback to this method is that it is not as fast as pseudo-random or pure random, since the transient part of the structure's response must be allowed to die out before each new ensemble average can be made. The time required for a comparable number of averages may be from two to three times as long. Still, in many practical measurement situations, periodic random provides the best solution in spite of the extra time required.

The advantages of periodic random are:

1. It is the best signal for exciting a system to determine its modal characteristics by curve fitting.

2. It, like pure random, gives the best linear approximation for a nonlinear system.

3. Both the input level and spectrum can be carefully controlled.

The disadvantages are:

1. It requires additional hardware over standard pure random measurements (DAC output from the computer).

2. It is slightly slower than standard random measurements, however, it is up to 10 times faster than swept sine testing methods.

Random Transient - The random transient excitation function is basically the previous "periodic random" modified so that it is totally observed transient. This is simply accomplished by requiring a dead band at the end (typically the last 20%) of each sample period of T seconds. The actual duration of the dead band must be adjusted for each test specimen so that the sampled data satisfy the criterion of a totally observed transient, i.e., no truncation of the measured response data in the sample period, T. This is fairly easy to accomplish if the test setup parameters establishing the duration of the T-second sample length allow sufficient frequency resolution to adequately define all modes in the excitation frequency range. This usually requires that Fourier transforms be obtained with block sizes of 4K time domain data points for typical aircraft structures. With the availability of new Fourier Analyzer systems with increased computer data space, block sizes of 8K time domain data points are becoming realizable.

The random transient excitation function exhibits all the advantages of periodic random. It has random amplitude and phase in the frequency domain. Each ensemble of the random transient is uncorrelated with previous ensembles.

Response nonlinearities are thus randomized from one ensemble to another such that the ensemble average should obtain the best linear estimate of the structural transfer function. Since each ensemble, when properly executed, is a "totally observed transient"; there are no leakage errors. The input level and frequency spectrum can be controlled. It does not have the severe time handicap of the periodic random requirement that one or several ensembles be wasted while establishing periodicity of the vibrating structure.(90)

Transient Signals

Impact - When the Fourier analyzer was first introduced it seemed as though impact testing was the answer to every frequency response tester's dreams. In theory it was possible to determine the frequency response of any structure simply by hitting it with a hammer. This was felt to be possible since an impact is an approximation to a unit impulse function which contains energy at all frequencies. However, when impact testing was first tried, it produced a variety of results. It seemed to work quite well in some cases and not at all in others.

A great deal of research has been conducted at the University of Cincinnati into the use of impact testing (225). This research has shown that impact testing can be one of the most useful testing techniques available if the proper restrictions are applied as to the type of structure, selection of impactors and the signal processing techniques used.

There are two very important structural characteristics to be considered in impacting: linearity and damping. Since impact has a very high ratio of peak to

rms energy content, it tends to excite nonlinearities in a system. For this reason, impacting does not work well on a nonlinear system. The amount of damping in the system is also important. If there is too little damping, the response signal will not decay to zero within the sampling time and severe leakage errors will result. If there is too much damping in the system, noise becomes a more significant problem. This is because the response signal decays to zero shortly after the start of sampling but any noise will be present throughout the total time. Both of these conditions can be improved by the use of the proper signal processing techniques.

The problems with impact testing are caused by the pulse-like nature of the impact signal. It has a very high peak value with very short duration. This causes the force to overdrive (i.e., excite the nonlinearities) the system while putting very little total energy into it. As a result, nonlinear response is greatly exaggerated while the signal to noise ratio for the entire measurement is very low.

Impact Testing Technique - Unlike the exciter techniques, impact testing requires much more care in setup and procedure to obtain good results. One serious problem, caused by the high force levels involved, is that of overdriving amplifiers, filters, digitizers, and the system itself. The possibility of this occurring and going unnoticed is compounded by the anti-aliasing filters used with digital processing systems. These filters can make even overloaded signals look good. Extreme care must be used to be sure overloads do not occur.

Mounting of transducers is also very important. Because of the high force levels involved, high local accelerations can occur. For this reason, methods of accelerometer attachment which may work well for other excitation methods do not work with impacting. Magnets, for example, are very bad because of their tendency to bounce.

The proper choice of an impact hammer is also important. The prime consideration is what frequency range is to be excited. The frequency content of an impulse is inversely proportional to the width of the pulse. Factors which affect the pulse width are the weight of the hammer, the hardness of the hammer tip, the technique of the person swinging the hammer and the mass and stiffness of the structure under test. Figures 2 and 3 show the effect of different hammers, tips and masses on the excitation force spectrum.

If proper care is exercised in the test setup and procedure and with the proper signal processing techniques, impact testing can be a very useful testing technique.

The advantages of impact testing are:

1. Setup and fixturing time are a minimum of all the excitation techniques.

2. Equipment requirements are the least of all the testing methods.

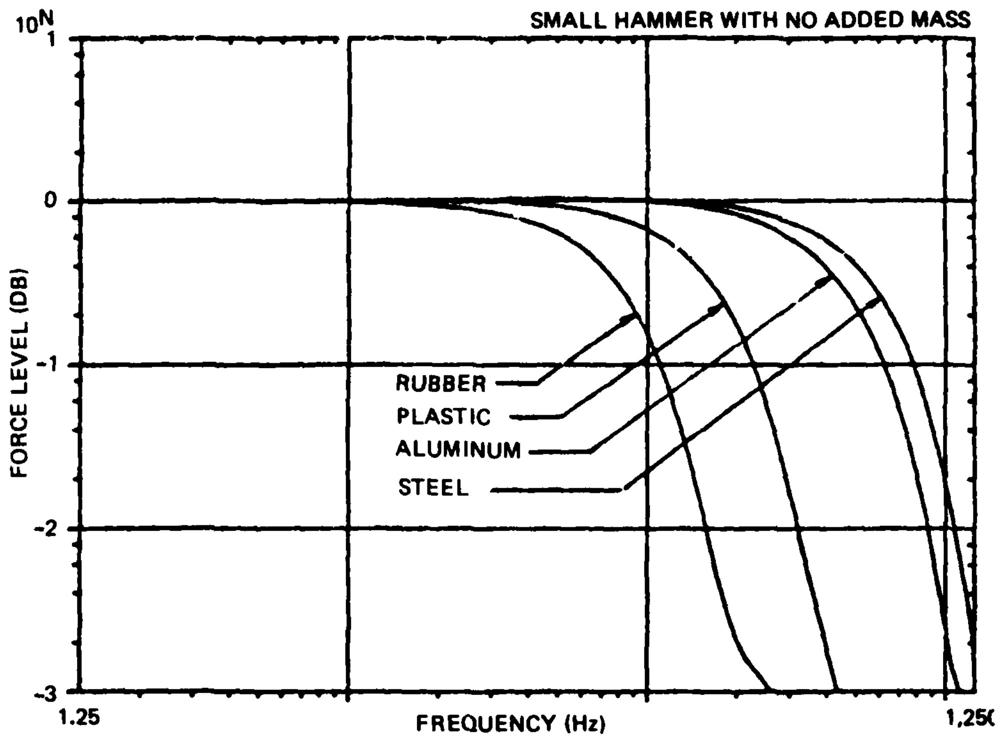

Figure 2. Effect of Tip Hardness on Force Spectrum

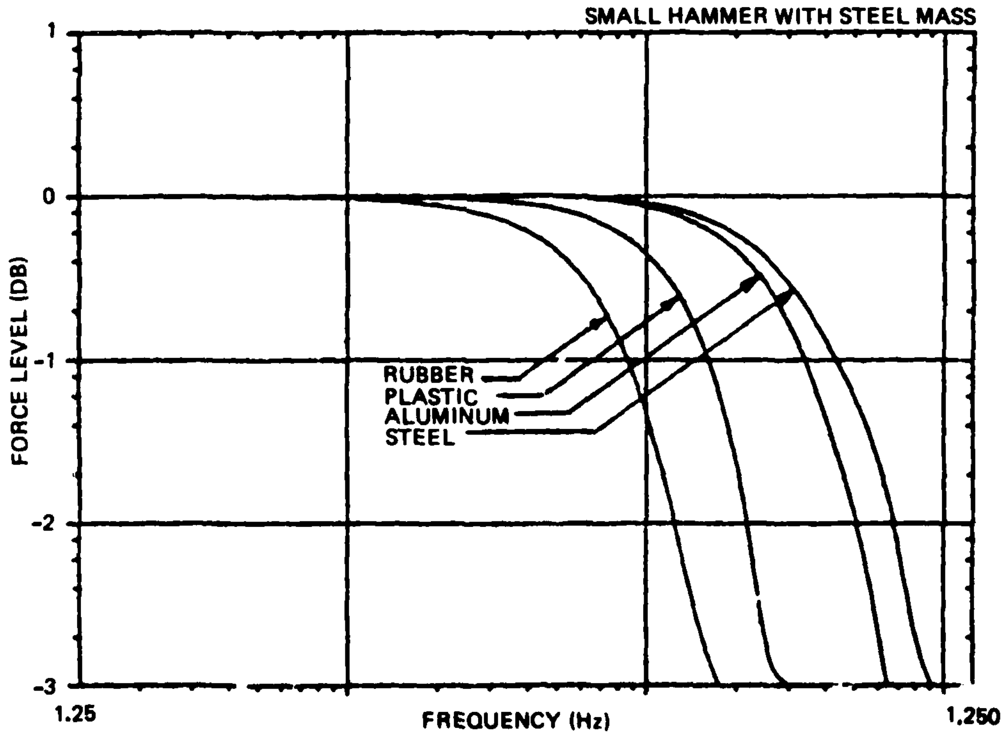

Figure 3. Effect of Mass on Force Spectrum

3. It is the fastest test method for low noise environments.

4. It is ideal for use in tight quarters where an exciter will not fit.

Its disadvantages are:

1. It has a very high peak to rms energy ratio and is therefore not suitable for nonlinear systems.

2. Since little energy is input into the system, it has poor signal to noise characteristics.

3. Special care must be taken to eliminate overloads to system, signal processing equipment and/or the data analysis equipment.

Unit Step Function Testing (Step Relaxation) - A second type of transient input frequently used for measuring the frequency response of a system consists of a unit step function input. A unit step function is normally generated by preloading the structure with a measured force through a cable and then releasing the cable.

For aircraft testing this technique is of limited usefulness. Therefore, only a very brief list of its advantages and disadvantages are given below:

Its advantages are:

1. It can be used on very small or large structures.

2. The direction and magnitude of the force vector can easily be controlled.

3. It has superior low frequency energy content.

Its major disadvantage is that it is difficult to implement on normal structures.

A more detailed complete evaluation of this type of excitation can be found in Reference 225.

Chirps (Fast Sine Sweeps) - A chirp is a nonperiodic fast sine sweep where the sweep rate exceeds the quasi-steady state condition necessary for swept sine testing. It has limited use for aircraft testing where the excitation signal is supplied by an exciter system. However, it is used when operating inputs excite the system. This will be briefly discussed in the following section.

Operating Inputs

Operating inputs would appear to be an ideal excitation source for measuring the frequency response of a system where the actual force input due to operation is used to excite the system. Unfortunately, except for simple cases the input forces are very difficult to measure.

Successful operating inputs have been unbalances in rotating machinery and aircraft control surfaces shaking an airplane via inertia forces. In the latter case the operating command was derived from the stability augmentation system computer and was actuated through the normal operating flight control system. Signal processing for operating inputs is identical to that for random inputs.

A Comment On Linearity

In the preceeding paragraphs the importance of exciting the structure to minimize nonlinear effects has been noted. This importance is a direct consequence of the way the data will be used. In general, the goal of the engineer involved in a structural dynamics test is to extract the best estimates of the modal parameters of the structure, i.e., each mode's natural frequency, damping factor, and characteristic shape. It is this information which is used to study, alter, and improve the dynamic behavior of the structure.

Nearly all techniques in use today to extract modal parameters are based on linear structural models. In general, a linear model is fitted to the measured data by some form of curve fitting method. Any nonlinear distortion in the measured data will impair the ability of the analytical curve fitting algorithm to accurately extract modal parameters.

It is noted that evaluation of nonlinearities is not trivial. The study of a structure's nonlinear characteristics by exciting it with a sinusoidal source where the frequency and amplitude can be accurately controlled is occasionally required. However, if one wishes to extract modal parameters, the structure must be excited such that it's linear characteristics may be measured.

3.1.1.2 Test Setup

The test setup should be supported by a pretest analysis that identifies the dynamic characteristics of the test article relative to various excitation inputs, exciter locations and transducer positions. This procedure maximizes the success of the test. In the absence of a pretest analysis, experience, good test practice and procedures, and additional test data must suffice. The important aspects of the test setup include aircraft suspension, excitation equipment and technique, and transducers.

Aircraft Suspension

The suspension of the aircraft falls into three categories: (1) frequency separation techniques to achieve nearly free-free modes, (2) known or measured boundary conditions, and (3) a clamped condition. In any event the boundary condition must be well understood so that interaction between the structure and the constraint can be accounted for in the test results. Considerations of the aircraft suspension is simplified when included as a part of a pre-test analysis. Without pre-test analysis, a suspension system that introduces little contamination of the deformation modes of the test article or whose characteristics are well understood is essential.

Frequency Separation Techniques - The frequency separation techniques in common usage attempt to obtain free-free modes of the structure by achieving a separation between the fundamental mode of the aircraft and the rigid modes of the aircraft on the suspension. This implies that the constraints are very lightly

damped and well separated in frequency from the airplane modes. Various techniques include testing on under-inflated tires with the landing ge·· effectively bottomed, suspending the aircraft on bungee cord, suspension on commercially available air springs and the use of specially designed support systems such as mechanical springs. The choice of technique here is dependent on the overall size and weight of the aircraft as well as its fundamental mode. Care must be taken so that the total suspension system does not introduce modes in the frequency range of the test article.

Known or Measured Boundary Conditions - The free-free techniques such as under-inflated tires, air springs, bungee cord and mechanical springs can also represent known or measured boundary conditions. In these cases the effects of the known or measured boundary conditions can be used in a pretest or post-test analysis to compute the mathematical model of the test aircraft.

The "Clamped Condition" - In this case one attempts to achieve a cantilevered or near-cantilevered boundary condition. A free-free airplane model is obtained from the measured modal parameters by including rigid body degrees of freedom in a post test analysis. The clamped condition is the most difficult boundary condition to achieve and may or may not be successful. This technique is not recommended for aircraft suspension, but may be suitable for testing airplane components.

Excitation Equipment

Excitation equipment falls into two main categories: shakers and impulsive exciters. Both categories are recommended and their use is dictated by the test article and personal preference.

Shakers - Shakers are categorized mainly as electromagnetic, hydraulic, air and inertia. Electromagnetic and hydraulic are used for most applications. Air shakers are generally quite limited and only used in applications where the structure is so light that no single attachment to the structure can be made. Inertia shakers are not usually used in ground vibration testing of aircraft but quite often have application in flight flutter testing. The power requirements for the shakers can best be determined by pre-test analysis, however, when a pre-test analysis is not available experience must suffice.

Impulsive Exciters - Typical impulsive exciters are instrumented hammers, bonkers and step relaxation equipment. The use of these techniques all require measurement of the force imparted to the structure. The use of bonkers, which are explosive devices such as shot shells, is somewhat limited in aircraft testing where they have been mainly used as flight flutter exciters. The use has probably been supplanted by the use of aerodynamic vanes for that purpose (90).

Instrumented hammer techniques are in wide usage in industry for impact testing. Their use can be restricted by local structure loading requirements but they have been used on very large structures such as transmission towers and small and lightweight structures such as flutter models. One selects an appropriate hammer for each application.

Step relaxation techniques can be used in some applications where hammer techniques are inappropriate. With this method a measured impulse is imparted to the structure under test by pulling on it with a known force and then impulsively releasing, such as with a cut string.

Sensors

The selection of transducers may cover a wide range. Accelerometers, velocity sensors, strain-gages, displacement sensors and force transducers are all appropriate. Generally, accelerometers are recommended for most aircraft testing. Accelerometer selection is dependent on the frequency resolution required for the aircraft under test. When aircraft with low frequencies are being tested, servo type accelerometers or similar equipment with flat response down to DC are required. If resolution to only 5 Hz is necessary, less expensive accelerometers are used. The use of many fixed accelerometers are recommended for large aircraft applications rather than the use of roving pickups because of the cost of time on test. Another advantage is in being able to format the test data display of vibration modes during the test.

3.1.1.3 Data Handling

Two data collection techniques are in use; a standard analogue technique and a more automated state-of-the-art method using an analog to digital converter and a multiplexer. The latter technique requires more specialized equipment. This includes off-the-shelf 32-channel equipment that greatly improves the efficiencies of data collection and processing.

The standard analogue technique acquires time domain data of all transducers including the excitation signal, a data ready pulse and time code. The data is stored to an analog tape recorder. Any one accelerometer is monitored on line and provides a check of the quality of the measurement in the frequency domain. The coherence function is also calculated and examined for each measurement.

The data acquisition is handled using a computer which is also used to provide the excitation signals and a synchronous data ready pulse signaling the start of each separate test ensemble.

The data is collected over a time period, T, chosen for each sample of data such that the structural response has died out within the time period and that the frequency resolution, 1/T, is sufficiently small to adequately define the resonant peaks. Generally, the frequency resolution should be about one-fourth the half power point bandwidth of the resonant peaks.

Considerable improvements can be implemented in data acquisition systems via the new generation of off-the-shelf hardware. Autoranging amplifiers, analog-to-digital converters, digital link recording and computer-driven CRT's can be integrated into a computer controlled system with little or no development work. Data management is greatly simplified by using a computer system with a real time executive.

3.1.1.4 Data Processing

Computer Hardware

The computer equipment must be able to perform Fast Fourier Transforms, digital signal processing, curve fitting and test control. Although these functions are available in signal analyzer equipment, the minicomputer based modal analysis computer system is preferred because of its greater capability and versatility.

Computer Software

Data processing to be performed consists of calculation of the frequency response function from the measured data, curve fitting the frequency response function, calculation of the modal parameters (frequency, damping, modeshape amplitude and phase, mass) and data display. Commercial software systems are available for measurement and data processing.

The data generated will be output in printed arrays and/or animated mode shapes in a CRT display. Display coordinates for each transducer will be defined. The graphical displays will show the entire deformed structure relative to its undeformed shape or vector displays at each transducer coordinate. Hard copies of the CRT display will be made.

3.1.1.5 System Checks

System checks are controlled by a series of handbook procedures. These checks cover all aspects of the GVT, in addition to procedures for checking the computer based systems.

3.1.1.6 Signal Processing Techniques

Several signal processing techniques can be used to improve signal to noise ratio problems. One common source of noise on both the force and response signals is electrical noise occurring at harmonics of the power line frequency. This noise can be minimized by choosing a sample period such that the power line harmonics are exactly periodic within the sample window, i.e., the total measurement time is an integer multiple of 1/60 second. This will cause them to fall exactly on a single spectral line of the analyzer where they can be modified without affecting other data. One modification would be to set the power line harmonics to the average value of the two adjacent spectral lines. Of course this technique is only useful if the data of interest do not fall at the power line frequencies.

Another source of noise is digitizer or "bit" noise. This is characterized by random one or two bit excursions of the signal about zero volts. Figure 4 illustrates this with a greatly magnified force pulse. Intuitively it would seem that this noise is insignificant when compared with the amplitude of the force pulse. However, when the energy associated with the noise is compared with the energy of the force pulse the noise becomes very significant.

A technique which can be used to minimize the digitizer noise on the force signal involves multiplying the time domain signal by a window or weighting function as shown in Figure 5. The characteristics of this window are that it has unity amplitude for the duration of the force and a smooth transition to zero after the force pulse is ended. Since the force signal is known to be zero after the impactor has left the surface, no measurement errors are introduced by using this technique. The effect of using this window is shown in Figures 6 and 7.

For severe noise problems such as might be encountered in analyzing tape recorded data, curve fitting techniques can be used to clean up the force signal. Figure 8 shows a force spectrum from an impact with a signal to noise ratio of one (i.e., the rms noise level is equal to the rms signal level). Figure 9 shows the same force spectrum after it has been fitted using a complex exponential algorithm using five degrees of freedom (225, 226). Figure 10 shows a spectrum from the same force signal with no added noise. It can be seen that this method can recover a reasonable force signal even from a force pulse with very high noise.

Noise on the response signal is handled much like the digitizer noise on the force signal except that a different weighting function is used. With a transient input, the signal level at the beginning of the sample is much higher than at the end of the sample. Assuming a uniform noise level, the signal to noise ratio decreases as the signal level decreases. Thus the data at the beginning of the sample is much more reliable than that at the end. For this reason the weighting function shown in Figure 11 is used. Unlike the force window, this window does have an effect on the measured frequency response. However, the effects are known and correctable. The window has the form of $Ae^{-\alpha t}$ and its

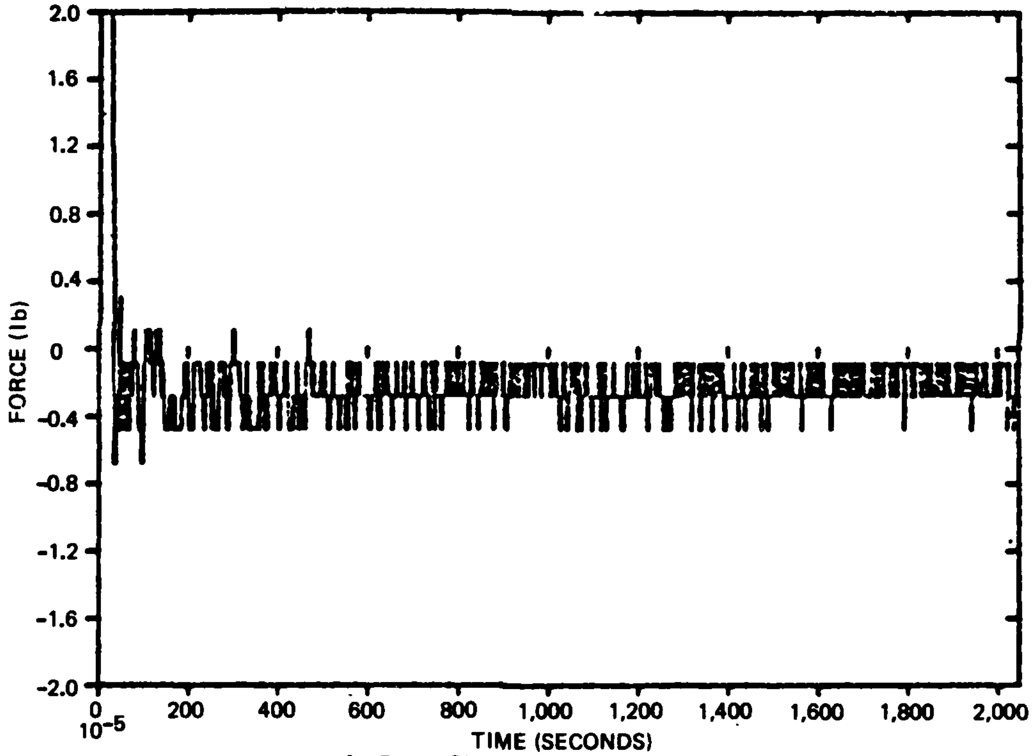

Figure 4. Force Signal Showing Digitizer Noise

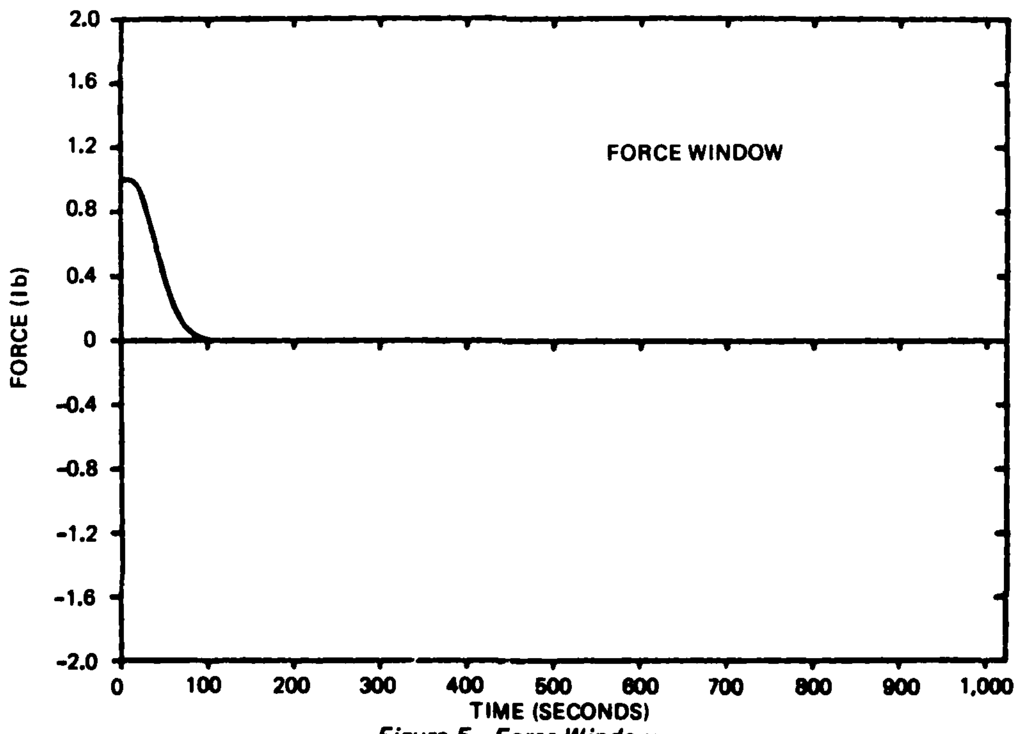

Figure 5. Force Window

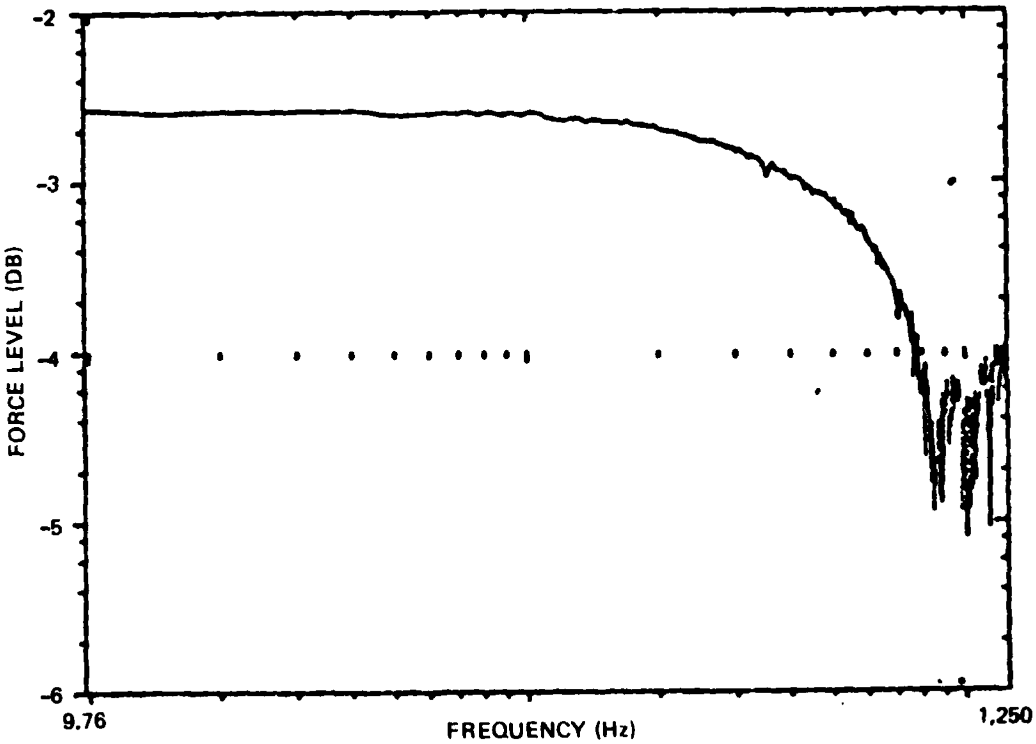

Figure 6. Force Spectrum With No Window Used

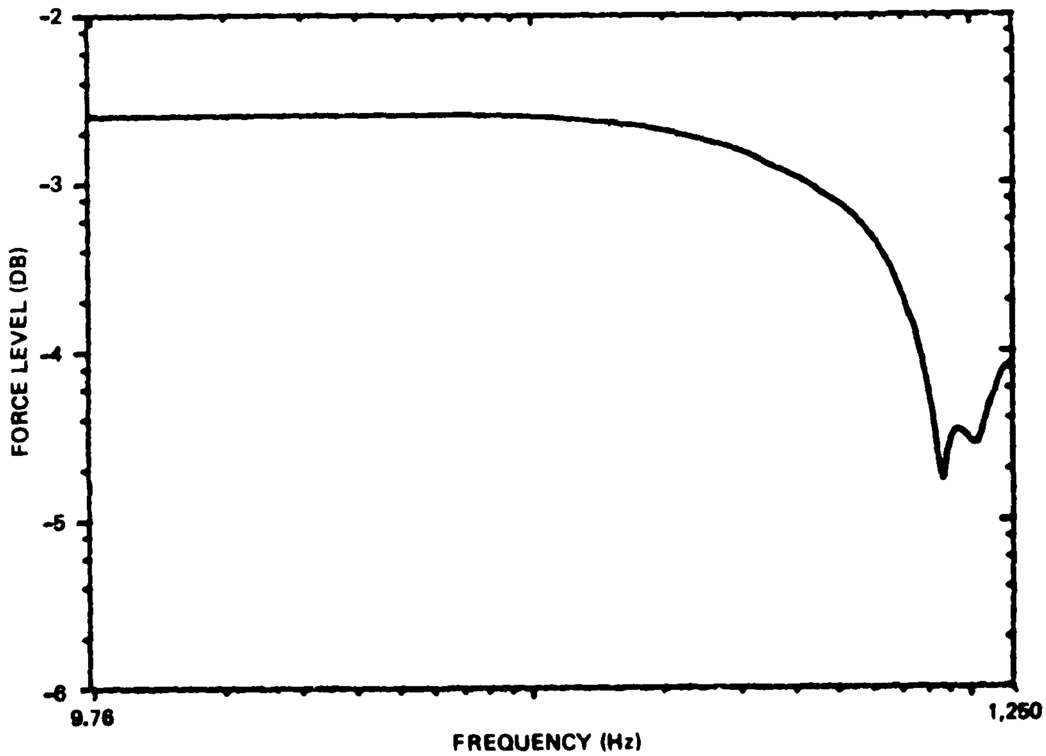

Figure 7. Force Spectrum Smoothed With Force Window

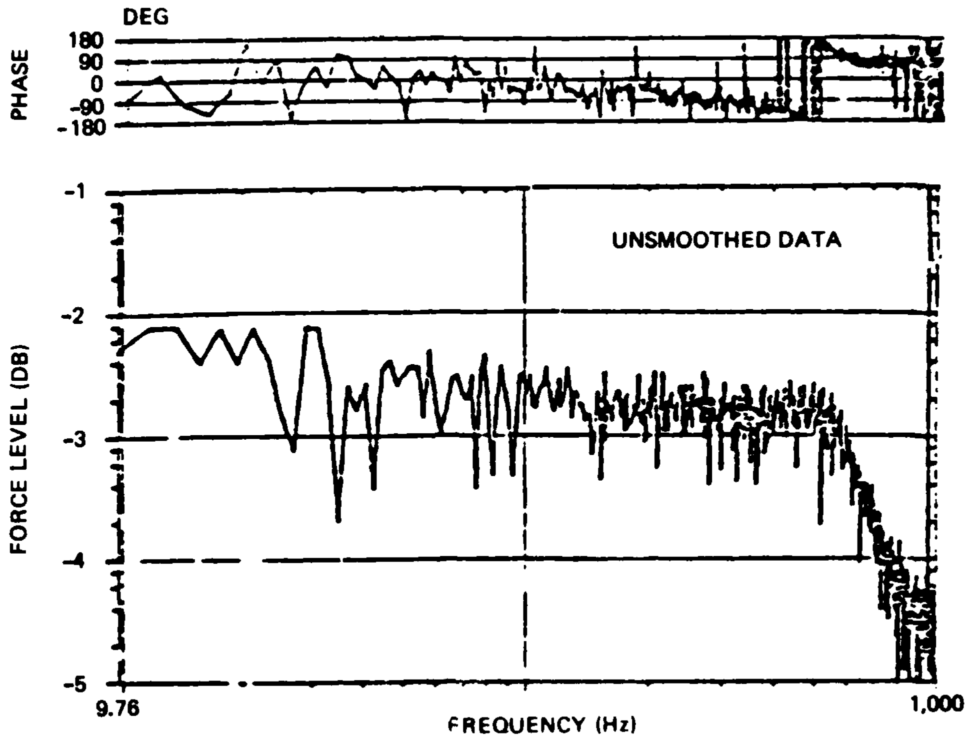

Figure 8. Force Spectrum Versus Frequency - Unsmoothed Data

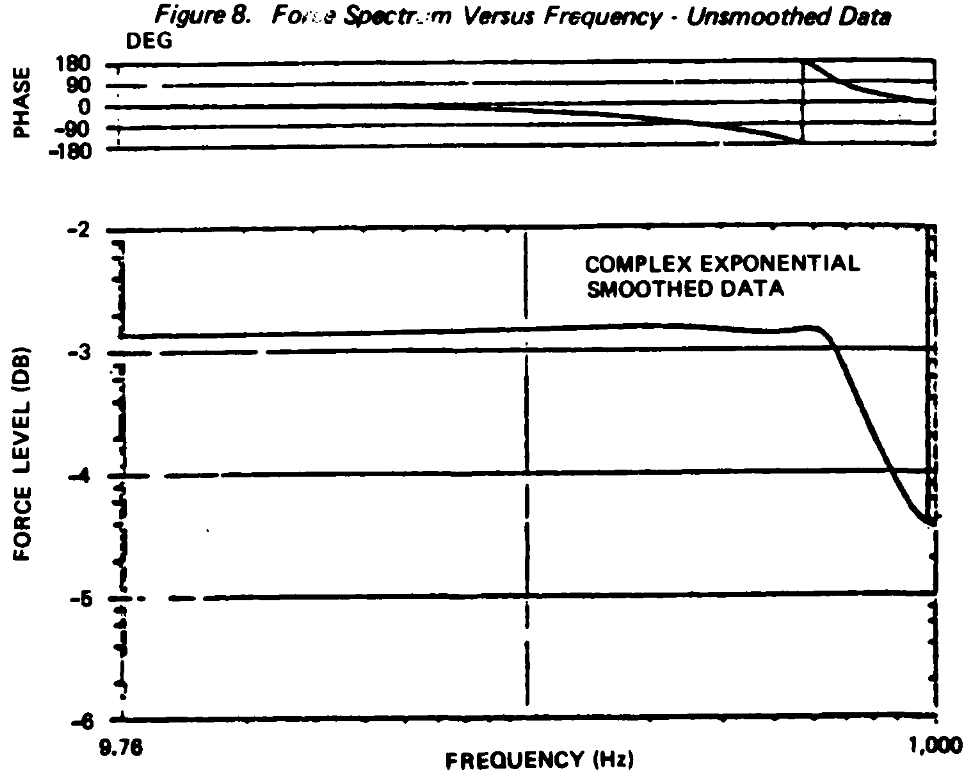

Figure 9. Force Spectrum Versus Frequency - Complex Exponential Smoothed Data

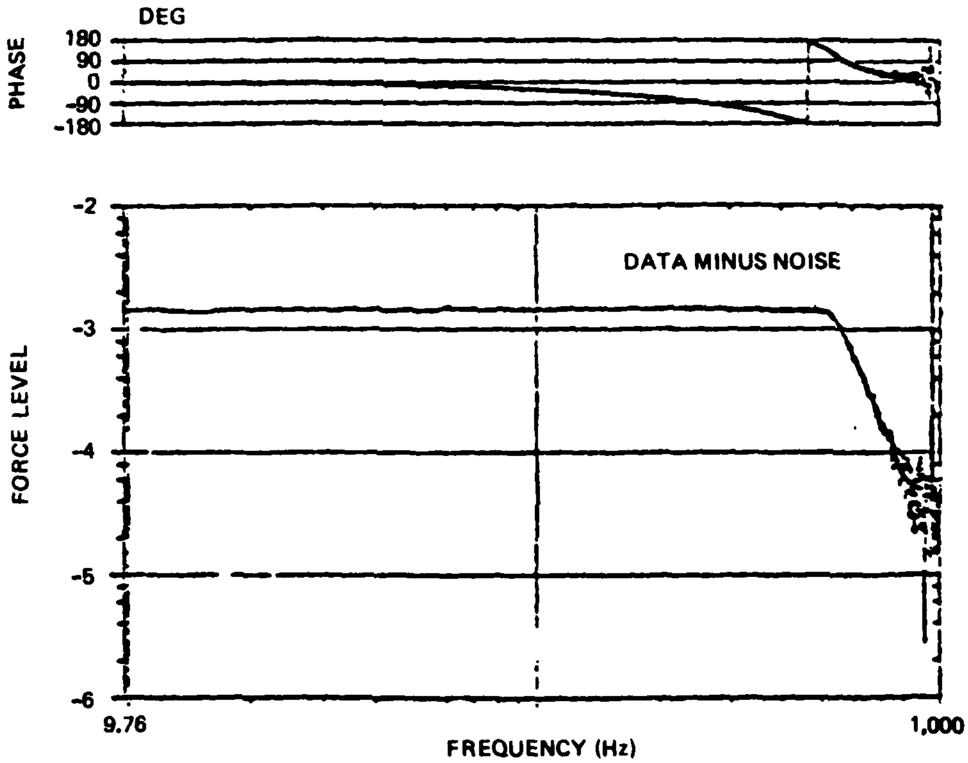

Figure 10. Force Spectrum Versus Frequency - Data Minus Noise

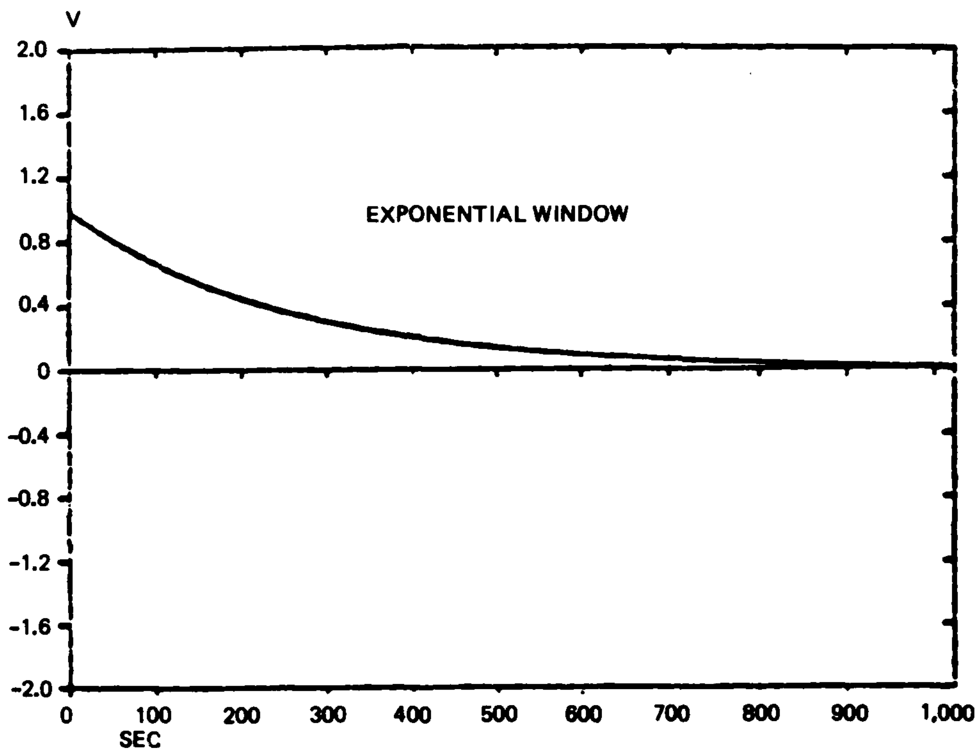

Figure 11. Exponential Window

effect is equivalent to adding damping to the system. If the actual damping in the system is required, the damping added by the window can be easily subtracted off.

3.1.2 Interpretation Phase

3.1.2.1 Introduction to Modal Analysis*

Review of Modal Analysis Using Transfer Functions

Modes of vibration have already been defined in terms of the eigenvalues and eigenvectors of the time domain equations of motion. Since the transfer function method of modal testing is based upon the measurement of frequency domain functions, it is next shown that modes of vibration can be defined by parameters of a transfer function matrix model of the structure, which is equivalent to the time domain model.

It should become clear from this analysis that during a typical modal test, <u>one row</u> or <u>column</u> of the transfer matrix model is being measured, and that this is sufficient information to identify all the parameters which define the modes of vibration. It should also become clear that a <u>complete</u> dynamic model can be constructed from the modal parameters.

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*This section is excerpted, with permission, from "Measurement and Analysis of the Dynamics of Mechanical Structures", a lecture by Mark H. Richardson.

Time Domain Model - In a measurement situation the actual input forces and responses for a finite number of degrees-of-freedom of the structure are measured. So if a model were constructed from the measurements involving these specific degrees-of-freedom, the model would give an accurate description of the structural dynamics involving those points. This is a different situation than with a finite element model where the degrees-of-freedom and the size and shape of the elements are chosen so as to approximate the dynamics of the structure as closely as possible.

The time domain structural dynamic model, as shown in Figure 12, exhibits the same form as the finite element model but, at least in principle, is an exact model of the structural dynamics if obtained from measurements.

Laplace Domain Model - We do not directly measure the time domain model of Figure 12, but rather its Laplace domain equivalent, shown in Figure 13.

In this model the inputs and responses of the structure are represented by their Laplace transforms. Time domain derivatives (i.e. velocity and acceleration) do not appear explicity in the Laplace domain model but are accounted for in the transfer functions. The transfer matrix contains transfer functions which describe the effect of an input at each degree-of-freedom (D.O.F.) upon the response at each D.O.F. Because the model is linear, the transformed total motion for any D.O.F. is the sum of each transformed input force multiplied by the transfer function between the input D.O.F. and the response D.O.F.

$$M\,\ddot{x}(t) + C\,\dot{x}(t) + K\,x(t) = f(t)$$

MASS MATRIX — ACCELERATION VECTOR — DAMPING MATRIX — VELOCITY VECTOR — STIFFNESS MATRIX — DISPLACEMENT VECTOR — APPLIED FORCE VECTOR

IF n-DEGREES-OF-FREEDOM ARE MEASURED ON THE STRUCTURE THEN THE VECTORS HAVE n-COMPONENTS AND THE MATRICES ARE $(n \times n)$.

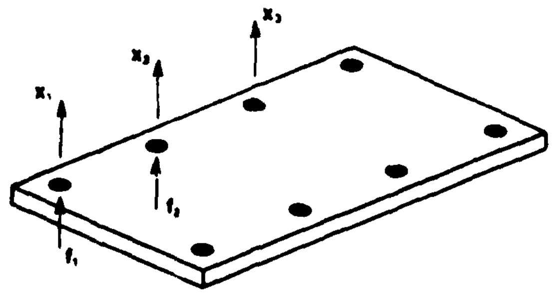


Figure 12. The Structure Dynamic Model (Time Domain)

$$\begin{bmatrix} X_1(s) \\ X_2(s) \\ \cdot \\ \cdot \\ \cdot \end{bmatrix} = \underbrace{\begin{bmatrix} h_{11}(s) & h_{12}(s) & \cdots \\ h_{21}(s) & \cdot & \\ \cdot & & \\ \cdot & & \\ h_{n1}(s) & & \end{bmatrix}}_{} \begin{bmatrix} F_1(s) \\ F_2(s) \\ \cdot \\ \cdot \\ \cdot \end{bmatrix}$$

LAPLACE TRANSFORMS OF RESPONSES — TRANSFER FUNCTION MATRIX — LAPLACE TRANSFORMS OF APPLIED FORCES

$$h_{n1}(s) = \frac{a_0 s^m + a_1 s^{m-1} + \cdots + a_m}{b_0 s^{2n} + b_1 s^{2n} + \cdots + b_{2n}}$$ TRANSFER FUNCTION

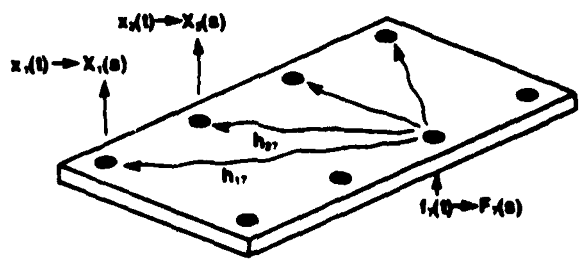


Figure 13. The Structure Dynamic Model (Laplace Domain)

For example,

$$X_1(S) = h_{11}(S)F_1(S) + h_{12}(S)F_2(S) + \ldots + h_{1n}(S)F_n(S)$$

Transfer Function of a Single Degree-of-Freedom - The Laplace variable is a complex number, normally denoted by $S = \sigma + j\omega$. Since the transfer function is a function of the S-variable, it too is complex valued. Plots of a typical transfer function on the S-plane are shown in Figure 14. Because it is complex, the transfer function is represented by its REAL and IMAGINARY parts or equivalently by its MAGNITUDE and PHASE. Note that in this case, the transfer function is *only* plotted over half of the S-plane, i.e., it is not plotted for any positive values of σ. This was done to give a clear picture of the transfer function values along the $j\omega$-axis. These values will become important later in this development.

Note also that the magnitude of the transfer function goes to infinity at two points in the S-plane. *These discontinuities are called* the POLES of the transfer function. These poles define resonant conditions on the structure which will "amplify" an input force. The location of these poles in the S-plane is defined by a FREQUENCY and DAMPING value as shown in Figure 15. Hence, the σ-axis and $j\omega$-axis of the S-plane have become known as the <u>damping</u> axis and the <u>frequency</u> axis respectively. The frequency and damping which define a pole in the S-plane are the frequency and damping of a mode of vibration of the structure.

Transfer Matrix in Partial Fraction Form - The elements of the transfer matrix can be written as ratios of polynomials as shown in Figure 13. With some minor assumptions, (explained later) the transfer matrix can be re-written in partial

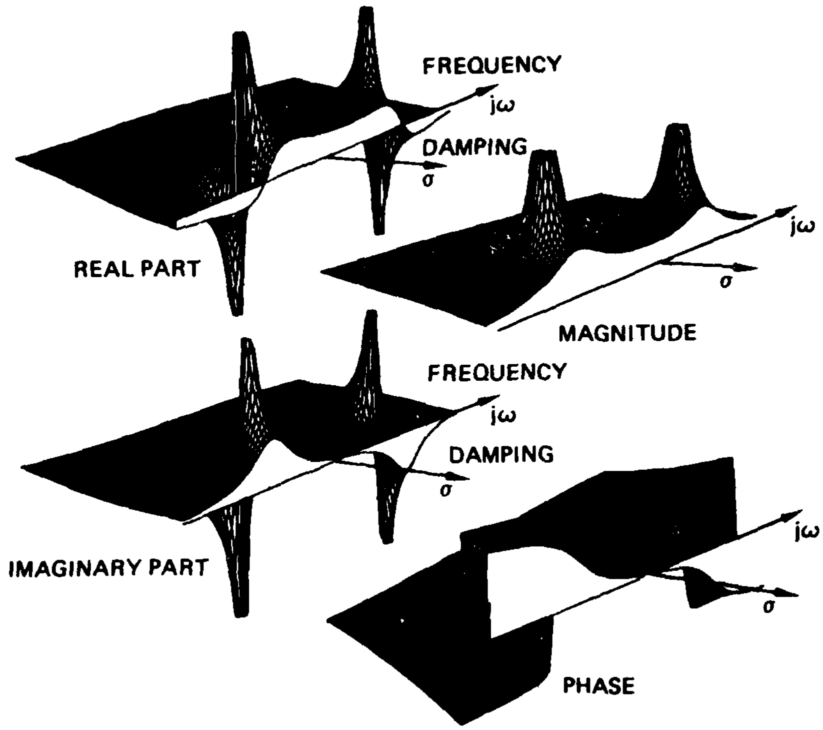
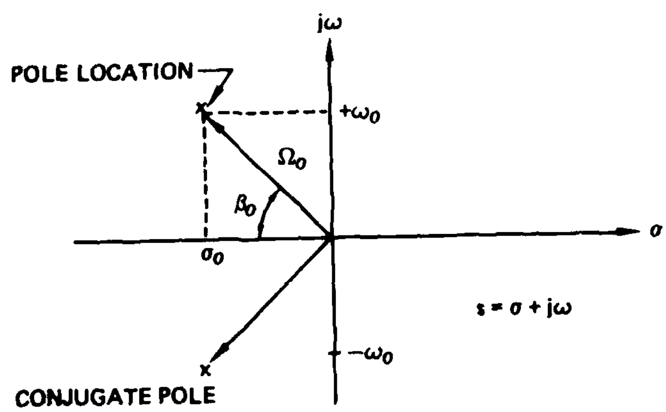


Figure 14. Transfer Function of a Single Degree-of-Freedom



σ_0 – Damping coefficient
ω_0 – Damped natural frequency
Ω_0 – Resonant (undamped) natural frequency
$\zeta_0 = \cos\beta_0$ – Damping factor (or percent of critical damping)

Figure 15. S-Plane Nomenclature

fraction form as shown in Figure 16. This form clearly shows the transfer function in terms of the parameters which describe its pole locations, namely $p_k = \sigma_k + j\omega_k$. For a model with n-degrees-of-freedom, it is clear that the transfer functions contain n-pole pairs (p_k, p_k*).

Two unique features of the partial fraction form are that all transfer functions contain the same denominator terms involving the S-variable, and that the numerators simply become constants (numbers) which are assembled into the RESIDUE matrix, and its conjugate matrix.

Transfer Matrix in Terms of Modal Parameters - After writing it in partial fraction form, the transfer function can be further simplified by writing the residue matrix in terms of a MODAL VECTOR (u_k) as shown in Figure 17.

The derivation of this form is given in References (156) or (170). This is a crucial step, for now we have reduced the transfer matrix (i.e. the entire dynamic model) to a parametric form involving only modal parameters. As stated in Figure 17, a mode of vibration is characterized by a pair of conjugate poles and a pair of conjugate mode vectors.

---

* - denotes complex conjugate

$$H(s) = \sum_{k=1}^{n} \left[\frac{r_k}{s - p_k} + \frac{r_k^*}{s - p_k^*} \right]$$

$p_k = \sigma_k + j\omega_k = k^{th}$ POLE

r_k – MATRIX OF RESIDUES FOR k^{th} POLE

$$r_k = \begin{bmatrix} r_{11}(k) & r_{12}(k) & \cdots \\ r_{21}(k) & \ddots & \\ \vdots & & \end{bmatrix} \quad (n \times n)$$

Figure 16. Transfer Function Matrix in Partial Fraction Form

$$H(s) = \sum_{k=1}^{n} \left[\frac{u_k u_k^t}{s - p_k} + \frac{u_k^* u_k^{*t}}{s - p_k^*} \right]$$

u_k – k^{th} MODAL VECTOR (n – DIMENSIONAL)

MODE OF VIBRATION: A MODE (k) IS CHARACTERIZED BY A PAIR OF CONJUGATE POLES (p_k, p_k^*) AND A PAIR OF CONJUGATE MODAL VECTORS (u_k, u_k^*).

Figure 17. Transfer Matrix in Terms of Modal Parameters

Note that the unique form of the residue matrix allows the entire (n x n) matrix to be defined once the n-dimensional mode vector is known. Furthermore, since every row and column contains the mode vector multiplied by a different component of itself, ONLY ONE ROW OR COLUMN of the residue matrix (and hence the transfer matrix) needs to be measured in order to identify the mode vector. A 2-dimensional case is written out in Figure 18 to illustrate this point.

The numerators of the first column of the transfer matrix are made up of the mode vector (u_{11}, u_{21}) multiplied by its first component (u_{11}), plus the conjugate mode vector (u_{11}, $*u_{21}*$) multiplied by its first component ($u_{11}*$), for mode #1. Similiarly, two more terms are added for mode #2. The denominators, which contain the pole locations (p_1, p_1*) and (p_2, p_2*), are the same for every transfer function in the matrix.

Modal Testing Implications - The modal testing implications of this final parametric form of the transfer function model are stated in Figure 19.

Normally only one row or column of the transfer matrix is measured in a modal test, although multiple row and column elements could be measured to obtain better estimates of the modal parameters. Reference (172) covers this subject.

The assumptions made in order to derive the parametric form of the model are explained in more detail in Reference (170). These assumptions can be satisfied in a large number of test situations but they must be kept in mind during a modal test since they can be easily violated when testing complex structures.

$$
H(s) = \underbrace{\frac{1}{s-p_1}\left[\begin{bmatrix} u_{11} \\ u_{21} \end{bmatrix}\begin{bmatrix} u_{11} & u_{21} \end{bmatrix}\right] + \frac{1}{s-p_1^*}\left[\begin{bmatrix} u_{11}^* \\ u_{21}^* \end{bmatrix}\begin{bmatrix} u_{11}^* & u_{21}^* \end{bmatrix}\right]}_{\text{MODE \#1}}
$$

$$
+
$$

$$
\underbrace{\frac{1}{s-p_2}\left[\begin{bmatrix} u_{12} \\ u_{22} \end{bmatrix}\begin{bmatrix} u_{12} & u_{22} \end{bmatrix}\right] - \frac{1}{s-p_2^*}\left[\begin{bmatrix} u_{12}^* \\ u_{22}^* \end{bmatrix}\begin{bmatrix} u_{12}^* & u_{22}^* \end{bmatrix}\right]}_{\text{MODE \#2}}
$$

Figure 18. Two Degree-of-Freedom Case

Modal parameters can be identified from one row or column of the transfer function matrix

Assumptions

1. Structural motion can be described by linear second order equations
2. The structure exhibits symmetry (or reciprocity)
3. Only one mode exists at each pole location
4. Modes are defined in a global sense

Figure 19. Modal Testing Implications

Transfer Function Measurement

In a test situation we do not actually measure the transfer function over the entire S-plane, but rather its values along the $j\omega$-axis.

These values are known as the FREQUENCY RESPONSE FUNCTION, as shown in Figure 20. Since the transfer function is an "analytic" function, its values throughout the S-plane can be inferred from its values along the $j\omega$-axis. More specifically, if we can identify the unknown modal parameters of a transfer function by "curve fitting" the analytical form in Figure 16 to measured values of the function along the $j\omega$-axis, then we can synthesize the function throughout the S-plane.

Alternative Forms of the Frequency Response - The frequency response function, being complex values, is represented by two numbers at each frequency. The so called CO-QUAD pilot, or real and imaginary parts, derives its origin from the days of swept sine testing when the real part was referred to as the COincident waveform and the imaginary part as the QUADrature waveform. The Bode plot, or log magnitude and phase vs. frequency, is named after H. W. Bode who made many contributions to the analysis of frequency response functions. (Many of Bode's techniques involved plotting these functions along a log-frequency axis.)

The Nyquist plot, or real vs. imaginary part, is named after the gentleman who popularized its use for determining the stability of linear systems. The Nichols plot, or log magnitude vs. phase angle, is named after N. B. Nichols who used such plots to analyze servo-mechanisms.

FREQUENCY RESPONSE FUNCTION

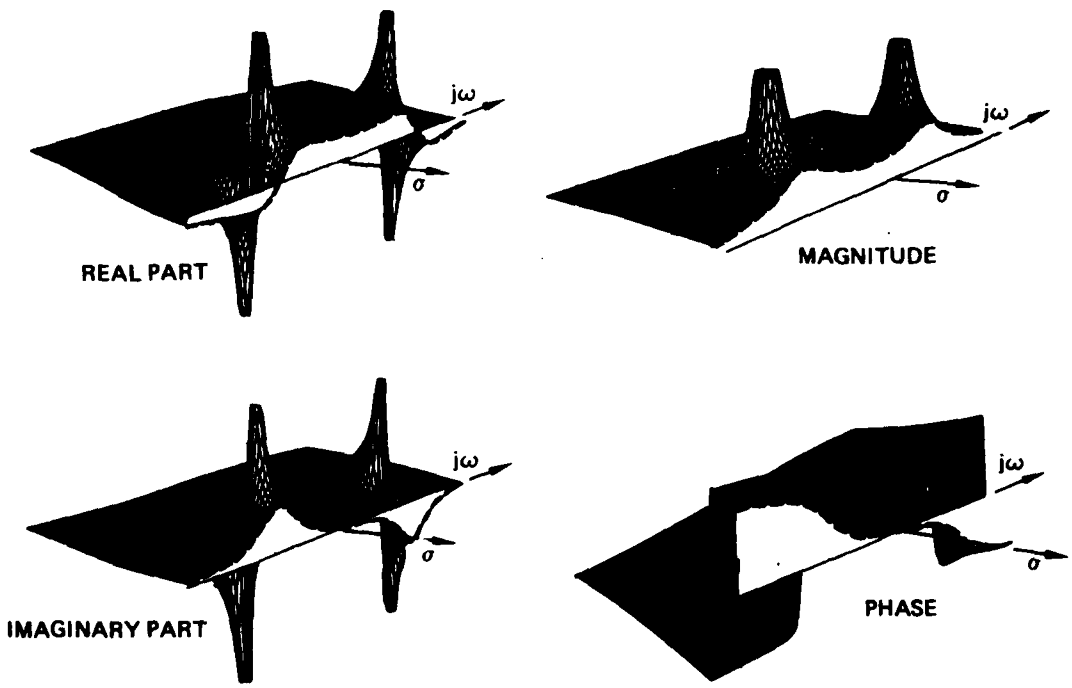


Figure 20. Transfer Function of a Single Degree-of-Freedom

Measuring Elements of the Transfer Matrix - The simplest way of measuring elements of the transfer matrix (i.e. frequency response functions) is to measure them one at a time, as shown in Figure 21. In this simple 2-dimensional case the frequency response function ($h_{11}(\omega)$) is measured by exciting the sdtructure at pt. #1 and measuring response at pt. #1. Then the function is formed by dividing the Fourier transform of the measured response motion ($X_1(\omega)$) by the Fourier transform of the measured input force ($F_1(\omega)$). Likewise the second element in the first row ($h_{12}(\omega)$) is measured by exciting the structure at pt. #2 and then dividing the Fourier transform of the response motion ($X_1(\omega)$) by the Fourier transform of the input force ($F_2(\omega)$). The second row of elements can be measured in a similar manner.

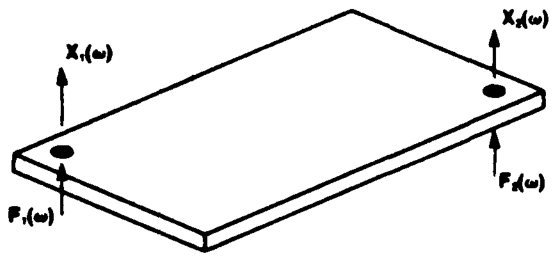
More sophisticated measurement methods involving multiple inputs and responses could be implemented, but this simplified single input-single output approach is most commonly used.

If time savings is a significant test objective, as it often is in larger modal tests, than test time can be significantly reduced by measuring a single input force and several response motions simulataneously. From this data, several transfer functions in a single column of the transfer matrix can be computed.

Modal Parameter Identification

Once a set of transfer functions has been measured from a structure, modal parameters are identified by "curve fitting" an ideal form for the transfer function to the measurement data.

$$\begin{bmatrix} X_1(\omega) \\ X_2(\omega) \end{bmatrix} = \begin{bmatrix} h_{11}(\omega) & h_{12}(\omega) \\ h_{21}(\omega) & h_{22}(\omega) \end{bmatrix} \begin{bmatrix} F_1(\omega) \\ F_2(\omega) \end{bmatrix}$$



FIRST ROW

$X_1(\omega) = h_{11}(\omega)\, F_1(\omega) + h_{12}(\omega)\, \cancelto{0}{F_2(\omega)}$ $\qquad h_{11}(\omega) = X_1(\omega)/F_1(\omega)$

$X_1(\omega) = h_{11}(\omega)\, \cancelto{0}{F_1(\omega)} + h_{12}(\omega)\, F_2(\omega)$ $\qquad h_{12}(\omega) = X_1(\omega)/F_2(\omega)$

SECOND ROW

$X_2(\omega) = h_{21}(\omega)\, F_1(\omega) + h_{22}(\omega)\, \cancelto{0}{F_2(\omega)}$ $\qquad h_{21}(\omega) = X_2(\omega)/F_1(\omega)$

$X_2(\omega) = h_{21}(\omega)\, \cancelto{0}{F_1(\omega)} + h_{22}(\omega)\, F_2(\omega)$ $\qquad h_{22}(\omega) = X_2(\omega)/F_2(\omega)$

Figure 21. Measuring Elements of the Transfer Matrix

As shown in Figure 22, at least one row or column of transfer functions from the transfer matrix must be measured in order to identify the mode shapes. The mode shapes, or mode vectors, are then assembled from the identified residues from each measurement at the same modal frequency.

Figure 23 shows a breakdown of a measurement into a summation of the contributions due to each of the modes of vibration. That is, the magnitude of the transfer function shown by the solid line in the figure, is really the summation of a number of magnitude functions shown by the dashed lines in the figure, each one due to a different mode of vibration.

The modal parameters (frequency, damping and residue), of a single mode can be identified by curve fitting the dashed line function corresponding to that mode. However, since only the solid line function was measured, it is clear that to *identify modal parameters accurately, all the parameters of all the modes must* be identified siultaneously by some method which fits a multiple mode form of the *transfer function to the data. This method is called a "multiple mode"* curve fitting method.

Many times, the accuracy of a multiple mode method is not required, so simple, easier-to-use methods known as "single mode" methods are used to identify the unknown parameters. A single mode method treats the data in the vicinity of a modal resonance peak as if it is due solely to a single mode of vibration. In other words the "tails" of the resonance curves from other modes are considered to have negligible contribution to the data in the vicinity of the resonance peak in question.

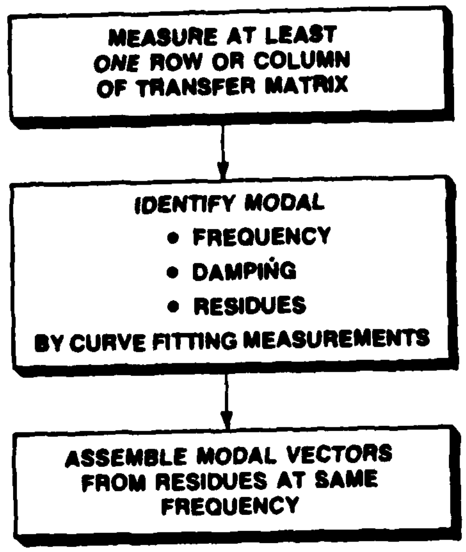
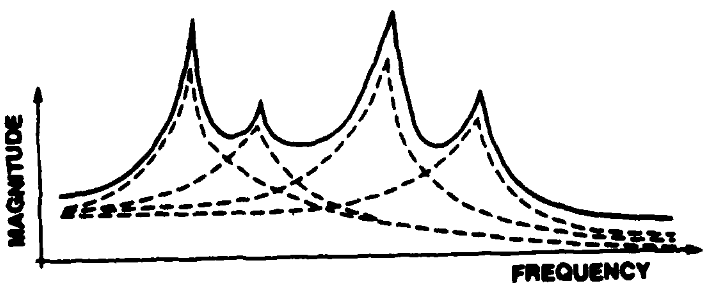


Figure 22. Modal Parameter Identification



MAGNITUDE OF A MULTI DEGREE-OF-FREEDOM SYSTEM TRANSFER FUNCTION

Figure 23. Multiple Degree-of-Freedom Transfer Function

The amount of error incurred with the use of single mode methods is dictated by the amount of "modal coupling" in the measurements.

In a light modal coupling case the measurement data in the vicinity of a modal resonance peak is predominantly due to that mode, and the influence of the other modes is minimal. In this case a single mode curve fitting method can give accurate results.

In a heavy modal coupling case the influence of the tails of other modes is not negligible, so a single mode method will incorrectly identify modal parameters.

3.1.2.2 Modal Parameter Determination

Once the frequency response information on the aircraft has been measured, the frequency response information is curve fit to identify the modal parameters. In the following sections, the modal parameter identification algorithms are described in detail. An algorithm is defined as a mathematical solution procedure. These procedures can, in general, be implemented on any computer. Care must be taken in discussing algorithms because the resulting computer program implementation is often also called (mistakenly) an algorithm. The curve fitting computer prcgrams are applied to selected portions of the frequency response functions. The analysis of one frequency response function could conceivably involve the use of all available curve fitting routines, each applied to a different frequency band. A typical frequency response function is shown on Figure 24.

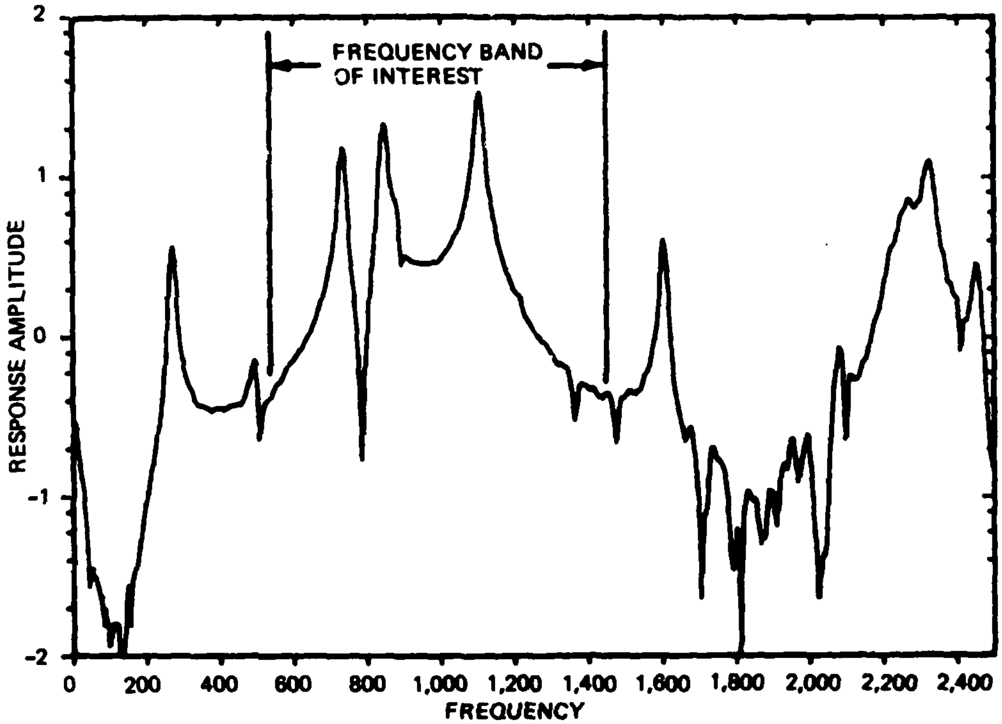


Figure 24. Typical Frequency Response Measurement

Single Degree of Freedom Approximations

In most modal parameter estimation schemes, the usual procedure is to first estimate the eigenvalues (natural frequencies and damping factors) and then to estimate the eigenvectors (modal coefficient). Note that the solution for the eigenvalues from measured frequency response information is mathematically a nonlinear process which, in general, greatly complicates the parameter estimation schemes, particularly the multiple degree of freedom cases.

The methods that are discussed in this section are all single degree of freedom approximation procedures. Many of the techniques are those which were used historically with swept sine testing techniques utilizing analog data analysis equipment. As a result of this type of equipment, the initial modal coefficients were output directly from the analog equipment (CO-QUAD Analyzers) or graphically determined from plotted frequency response information. With the advent of small, dedicated mini-computer systems it is possible to measure frequency response information and computationally determine the modal parameters. As a result of this improved computational capability, a large number of computational algorithms have been developed in recent years for computing modal information. In the next several sections each technique will be described as to its implementation, advantages, and disadvantages.

Amplitude Response - Perhaps the simplest modal estimation procedure is to measure the magnitude of the frequency response at one of the natural frequencies. The natural frequencies for this simple case can be determined by choosing the frequencies where the magnitude of the frequency response reaches a maximum. If

the damping coefficient is known, the modal coefficient is given by the following relationship:

$$B_{pq} = 2\zeta_r \left(\frac{X_p}{F_q} \right)_{peak} \tag{1}$$

The damping can be estimated by a number of different techniques, the most common being the half power points or by measuring the rate of change of the phase angle through the resonance peak (99).

If the damping coefficient is unknown, the terms on the right hand side of Equation 1 can be lumped together and used as the modal coefficient. In other words, the total response can be used as the modal coefficient. In fact, this is frequently done since the resulting mode differs only by a scale factor. This assumption depends upon the damping coefficient being a fixed global property of the system.

The only advantage of this technique is that a minimum amount of equipment can be used. If the structure is excited with a sine wave at the frequency of the resonance being investigated and the resulting response is filtered to eliminate the harmonic distortion, then a simple voltmeter can be used to measure the modal coefficient. An oscilloscope can be used to determine the phase. The main disadvantage of this technique is that it does a very poor job of separating modes.

Quadrature Response - In order to better separate the modes, the quadrature response can be measured. The quadrature response is the ninety degree out-of-phase response of the structure displacement or acceleration with respect to the input force.

The quadrature, or imaginary component of the frequency response of the system for a single degree of freedom reaches a maximum at the undamped natural frequency of the system and approaches zero away from the resonance frequency. It is this characteristic which helps to separate adjacent modes.

Again if the damping is known, the modal coefficient can be computed from the quadrature frequency response by the following relation:

$$B_{pq} = j2\zeta_r \left\{ \text{quad} \left(\frac{X_p}{F_q} \right)_{peak} \right\} \tag{2}$$

When the damping is unknown, by the same argument as before, the quadrature part of the response is used as the modal coefficient.

For cases where the system is lightly damped or the modes are well separated, the quadrature response is a very good technique.

The quadrature response technique has been. and still is, one of the more popular techniques for determining modal coefficients and is used extensively with the multiple shaker excitation approach. For troubleshooting cases, where it is not necessary to generate a modal model, the quadrature response technique will almost always give acceptable results. Typically, the frequency of the peak

quadrature response is chosen from a typical measurement or by constructing a summation of power spectrums of the quadrature responses from a number of measurements (Figure 25 and 26). Once the frequency is known, the value of the quadrature response at that frequency can be determined from the measured frequency response data at all points of interest on the structure.

The damping can be estimated by one of the multiple degree of freedom techniques described later or can be estimated using the rate of change of the phase angle, half power points, or magnification factor (Q) method.

Circle Fit - The original approach for this method was developed by Kennedy and Pancu (96) for systems with hysteretic damping characteristics. As will be shown, the method can be extended to the viscous damping cases and also can be extended to include complex modes by using Equation 13 with the following assumptions:

1. The modes are only weakly coupled in the range where one mode is predominant. The contribution of lower and higher modes can be approximated by a complex constant (R + jI).

2. The system is relatively lightly damped.

The frequency response of the structure in the frequency range where the r-th mode is predominant can be written as:

$$\frac{X_p}{F_q} = \frac{U_{pqr} + jV_{pqr}}{-\delta_r + j(\omega - \omega_{pr})} + R + jI \qquad (3)$$

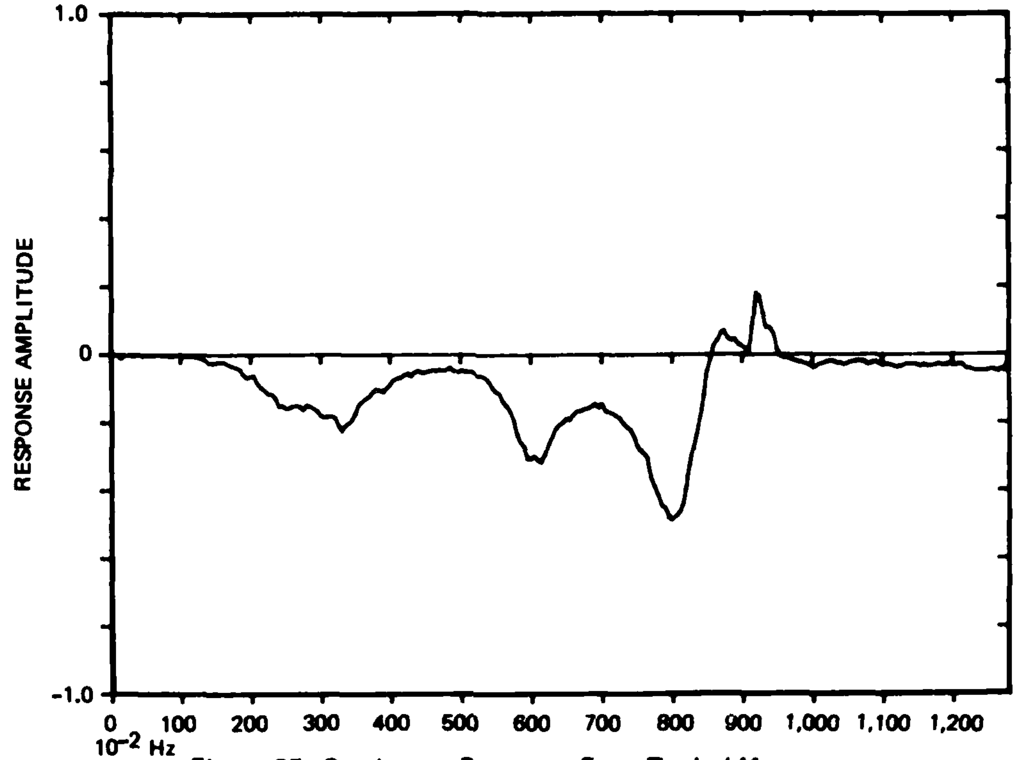


Figure 25. Quadrature Response For a Typical Measurement

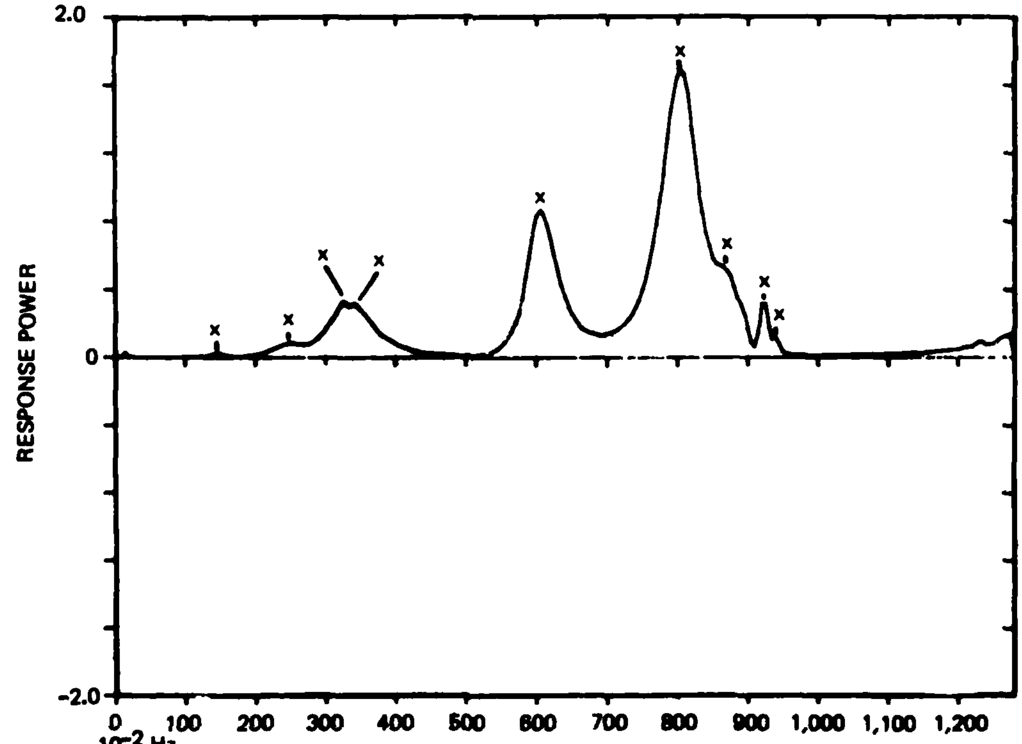


Figure 26. Power Spectrum of Quadrature Responses

where R+jI includes the contribution of the term associated with the conjugate eigenvalue. If the complex constant is neglected and the magnitude of the mode is set to unity, (U = 0 and V = -1 for a single degree of freedom, $\omega > 0$) the following relations can be obtained:

$$\mathrm{Re}\left\{\frac{X_p}{F_q}\right\} = -\frac{(\omega - \omega_{pr})}{(\omega - \omega_{pr})^2 + \delta_r^2} \tag{4}$$

$$\mathrm{Im}\left\{\frac{X_p}{F_q}\right\} = \frac{\delta_r}{(\omega - \omega_{pr})^2 + \delta_r^2} \tag{5}$$

and thus,

$$\left[\mathrm{Re}\left\{\frac{X_p}{F_q}\right\}\right]^2 + \left[\mathrm{Im}\left\{\frac{X_p}{F_q}\right\} - \frac{1}{2\delta_r}\right]^2 = \left[\frac{1}{2\delta_r}\right]^2 \tag{6}$$

In other words, the contribution of one mode to the general response can be represented in the Argand plane as a circle (Figure 27). Taking into account the complex constant and the complex modal coefficients, the coordinates of the center can be calculated as:

$$\left(R - \frac{U_{pqr}}{2\delta_r}, I - \frac{V_{pqr}}{2\delta_r}\right) \tag{7}$$

and the diameter as:

$$d = \frac{\sqrt{U_{pqr}^2 + V_{pqr}^2}}{\delta_r} \tag{8}$$

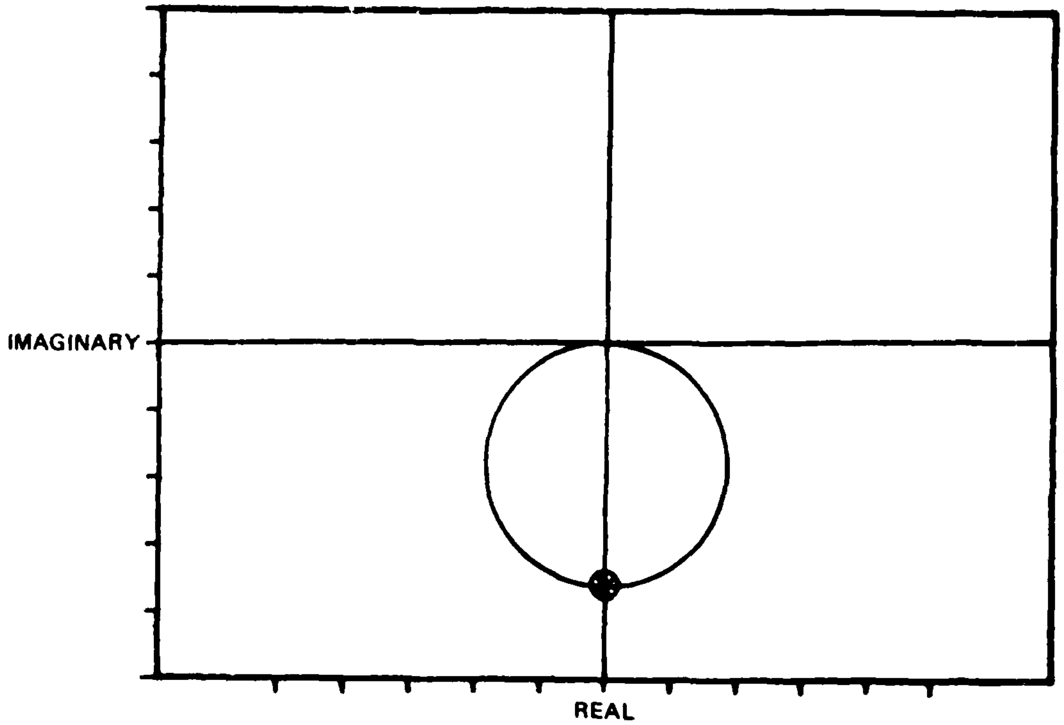


Figure 27. Argand Plane—Single Degree of Freedom

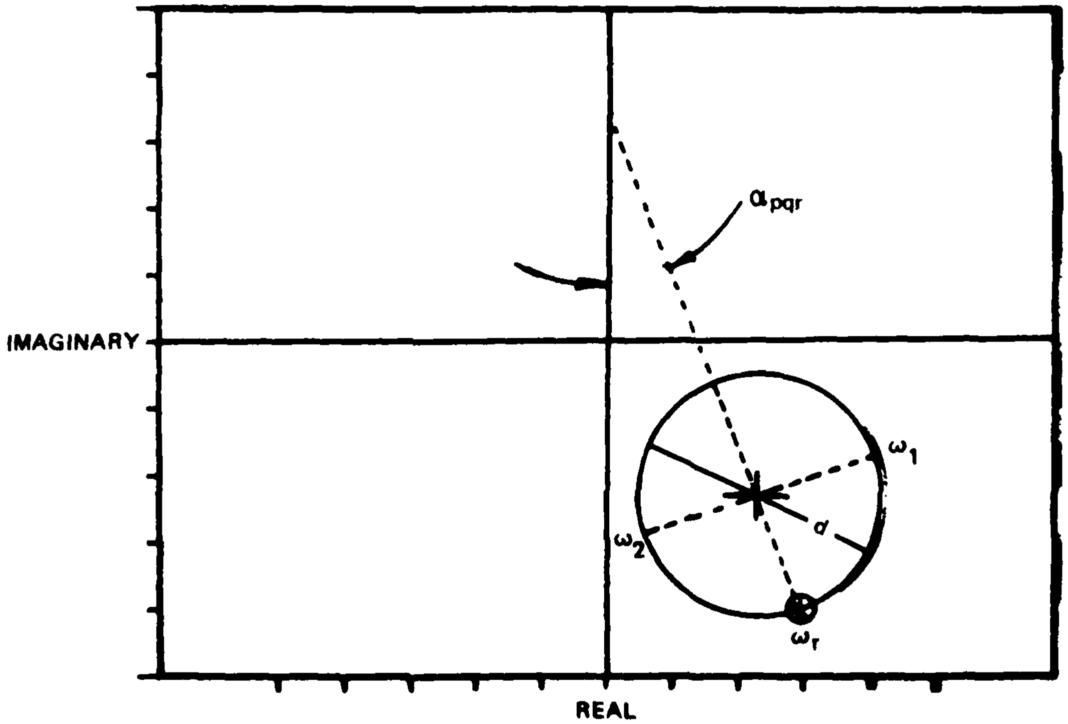


Figure 28. Characteristics of Kennedy-Pancu Circle Fit

The complex modal displacement vector expands or reduces the diameter and rotates the circle in the Argand plane. On the other hand, the complex constant (R+jI) will translate the center of the circle in the Argand plane (Figure 28).

A measure of the accuracy of this method is given by the shape of the frequency response in the region of the resonance: the more circular the curve, the more accurate the result.

It was shown in Reference 99 that the resonance frequency could be found where the variation of the phase angle as a function of frequency is a maximum:

$$\frac{\partial^2 \phi}{\partial \omega^2} = 0 \tag{9}$$

The damping ratio, ζ_r , can also be determined from the fitted circle. By locating the two frequencies $\omega 1$ and $\omega 2$ at ± 90 degrees with respect to the damped natural frequency (Figure 28), the damping can be calculated by the following relation:

$$\zeta_r = \left| \frac{\omega_1 - \omega_2}{2\omega_r} \right| \tag{10}$$

The diameter of the circle is proportional to the modulus of the residue:

$$d = \frac{1}{\delta_r} \left\| A_{pqr} \right\|^2 \tag{11}$$

The phase angle, α_{pqr}, of the complex modal coefficient can be calculated by passing a straight line through the point of the resonance frequency, ω_r , and

the center of the circle. The angle this line makes with the imaginary axis is equal to the phase angle of the complex modal coefficient:

$$\alpha_{pqr} = \arctan\left(\frac{U_{pqr}}{V_{pqr}}\right) = \frac{\pi}{2} + \arg\left(A_{pqr}\right) \tag{12}$$

Circle fitting typically is the next level of parameter estimation above quadrature response. It does a better job of separating coupled modes than the quadrature technique, but it, like most of the more complicated methods, can diverge and give very poor answers. In general, the method is fast and can be used to obtain complex modes, but in order to get the best possible results it should be used interactively. The center frequency and bandwidth used in the circle fit can be varied depending upon the amount of noise, the coupling of modes, and the damping of the mode. This choice of data points utilized in the circle fit gives different answer and the best answer becomes a judgement. As a result, the best answers are obtained by a skillful operator.

The normal procedure for using the circle fit is to first determine the natural frequency of the system using any one of a number of different procedures. The peaks in the quadrature response or the peaks in a summation of power spectrums (constructed from the quadrature response of all of the measurements) are very good indicators.

Using the least squares Circle Fit algorithm, a circle can be interactively fit to the measured frequency response data at the designated natural frequency. The damping ratio (ζ_r) as well as the modal coefficient (amplitude and phase) are defined by the location, diameter, and orientation of the circle.

In order to illustrate one of the more serious problems with circle fitting, the following example will be used. The first two modes of a cantilever beam will be determined using circle fitting. The mode shapes for the beam are shown in Figure 29. If an excitation force is applied at point one on the beam, the measured frequency response plots between point one and all other points are shown in Figure 30. In this figure the resonance frequencies are marked with a symbol and the bandwidth used in the circle fit are shown by the double line. The problem which is being illustrated shows in the measurement at point 2. At point 2 the modal contribution of mode 2 is nearly zero. The circle fit in this case is really a fit of the skirt of the first mode. Instead of getting a value near zero, a very large value is obtained. Due to this type of problem and due to bad estimates caused by noise, it is necessary to interactively fit the data with the Circle Fit algorithm.

Multiple Degree of Freedom Approximations

In studies carried out by Klosterman (99), Van Loon (208), and Richardson (170, 171, 227) a derivation is given for the general formula of the frequency response of a multiple degree of freedom system with viscous or hysteretic damping.

For general viscous damping, the frequency response for a multiple degree of freedom mechanical system can be written as:

$$\frac{X_p}{F_q} = \sum_{r=1}^{\infty} \left[\frac{A_{pqr}}{j\omega - \delta_r} + \frac{A^*_{pqr}}{j\omega - \delta_r^*} \right] \tag{13}$$

where

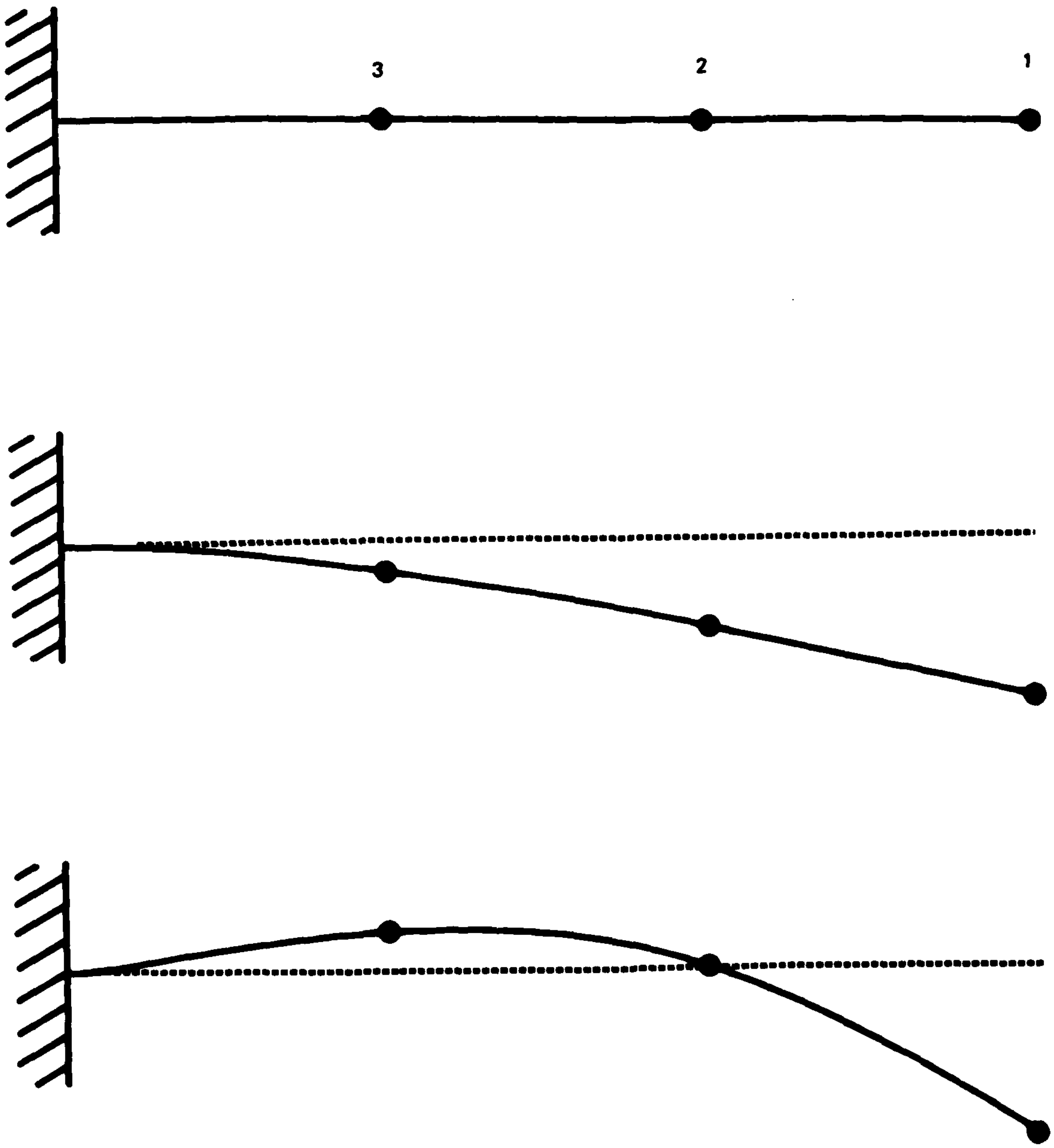


Figure 29. Cantilever Beam—Two Degrees of Freedom

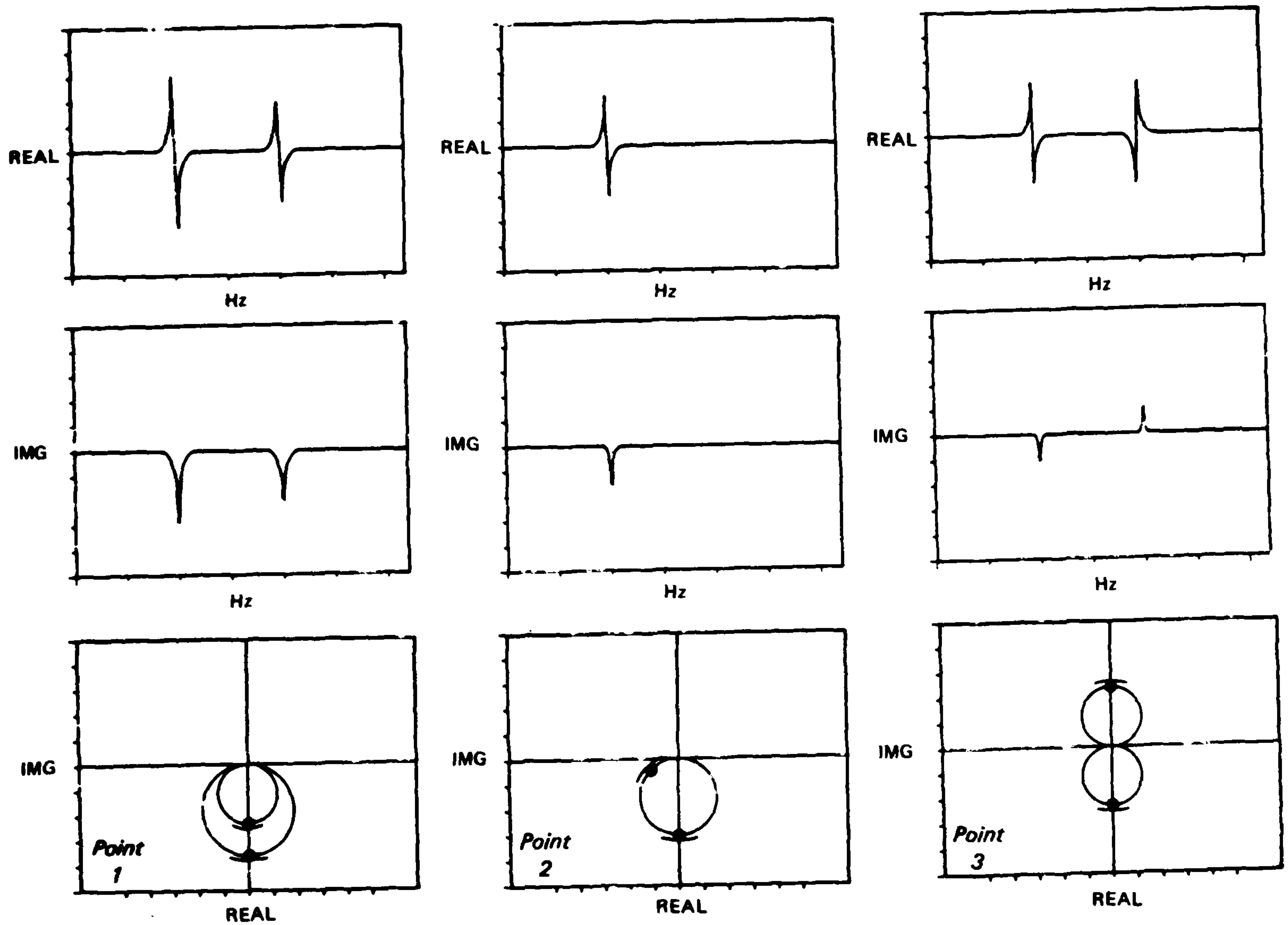


Figure 30. Cantilever Beam Frequency Response

x_p = response at point p,

F_q = input at point q,

$j = \sqrt{-1}$,

s_r = eigenvalue of r-th mode = $\delta_r + j\omega_{dr}$.

ω_{dr} = damped natural frequency of the r-th mode,

δ_r = decay rate of r-th mode (damping),

A_{pqr} = complex residue of r-th mode = $U_{pqr} + jV_{pqr}$.

Continuous systems have an infinite number of degrees of freedom, but, in general, only a finite number of modes can be used to describe the dynamic behavior of a system. The theoretical number of degrees of freedom can be reduced by using a finite frequency range (f_a,f_b). The frequency response could be separated into three partial sums, each covering the modal contribution corresponding to modes located in the frequency ranges $(0,f_a)$, (f_a,f_b) and (f_b,∞) (Figure 13). In the frequency range of interest, the modal parameters can be estimated to be consistent with Equation 13. In the lower and higher frequency ranges, residual terms can be included to handle modes in these ranges. In this case, Equation 13 can be rewritten as:

$$\frac{X_p}{F_q} = L_{pq} + \sum_{r=r_a}^{r_b} \left[\frac{A_{pqr}}{j\omega - s_r} + \frac{A^*_{pqr}}{j\omega - s^*_r} \right] + Z_{pq} \qquad (14)$$

where

r_a = lower mode index of the frequency range of interest,

r_b = upper mode index of the frequency range of interest,

L_{pq} = lower residual term, and

Z_{pq} = upper residual term.

Frequently, the lower residual term is called the inertia restraint, and the upper residual term is called the residual flexibility. These can be written as:

$$L_{pq} = -\frac{Y_{pq}}{\omega^2} = \mathrm{Re}\left\{\sum_{r=1}^{r_a-1}\left[\frac{A_{pqr}}{j\omega - s_r} + \frac{A^*_{pqr}}{j\omega - s_r^*}\right]\right\} \tag{15}$$

$$Z_{pq} = \mathrm{Re}\left\{\sum_{r=r_b+1}^{\infty}\left[\frac{A_{pqr}}{j\omega - s_r} + \frac{A^*_{pqr}}{j\omega - s_r^*}\right]\right\} \tag{16}$$

where

Re z = real part of a complex number z,

Y_{pq} = inertia restraint, and

Z_{pq} = residual flexibility.

Therefore, Equation 13 can be rewritten as:

$$\frac{X_p}{F_q} = -\frac{Y_{pq}}{\omega^2} + \sum_{r=r_a}^{r_b}\left[\frac{A_{pqr}}{j\omega - S_r} + \frac{A^*_{pqr}}{j\omega - S_r^*}\right] + Z_{pq} \tag{17}$$

An alternate way to write the frequency response in terms of its undamped natural frequency and damping coefficient is:

$$\frac{X_p}{F_q} = -\frac{Y_{pz}}{\omega^2} + \sum_{r=r_a}^{r_b}\frac{B_{pqr} + j\left(\frac{\omega}{\omega_r}\right)B'_{pqr}}{1 - \left(\frac{\omega}{\omega_r}\right)^2 + j2\zeta_r\left(\frac{\omega}{\omega_r}\right)} + Z_{pq} \tag{18}$$

where by definition,

$$\omega_r = \sqrt{\delta_r^2 + \omega_{dr}^2} \qquad B'_{pqr} = \frac{2U_{pqr}}{\omega_r} \tag{19}$$
$$\zeta_r = -\delta_r/\omega_r$$

$$B_{pqr} = -\frac{2\left(\delta_r U_{pqr} + \omega_{pr} V_{pqr}\right)}{\omega_r^2} \qquad (20)$$

The above terms have the units of compliance and as a result the numerator of Equation 18 is the "complex compliance". For the case of proportional damping, the equation for the frequency response has the more classical form:

$$\frac{X_p}{F_q} = -\frac{Y_{pq}}{\omega^2} + \sum_{r=r_a}^{r_b} \frac{B_{pqr}}{1 - \left(\frac{\omega}{\omega_r}\right)^2 + J2\zeta\left(\frac{\omega}{\omega_r}\right)} + Z_{pq} \qquad (21)$$

where

$$B_{pqr} = \text{modal compliance} = \frac{\text{displacement output}}{\text{force input}}$$

Many of the parameter estimation techniques that are used will assume that only one mode exists in the range of interest and all of the other modes appear as residual terms. For this case Equation 14 can be rewritten as:

$$\frac{X_p}{F_q} = -\frac{Y'_{pq}}{\omega^2} + \frac{A_{pq}}{j\omega - s} + \frac{A^*_{pq}}{j\omega - s^*} + Z'_{pq} \qquad (22)$$

or for the case of proportional damping as:

$$\frac{X_p}{F_q} = -\frac{Y'_{pq}}{\omega^2} + \frac{B_{pq}}{1 - \left(\frac{\omega}{\omega_r}\right)^2 + j2\zeta_r\left(\frac{\omega}{\omega_r}\right)} + Z'_{pq} \qquad (23)$$

Several of the curve fitting cases which will be discussed utilize the unit impulse response of the system. The unit impulse response is the Fourier transform of the frequency response. Therefore, a mathematical expression for the unit impulse response can be obtained by a Fourier transform of Equation 13:

$$h_{pq}(t) = \sum_{r=1}^{\infty}\left[A_{pqr}\, e^{s_r t} + A^*_{pqr}\, e^{s^*_r t}\right] \tag{24}$$

The remainder of this discussion in this report will involve experimentally determining the modal parameters by using a parameter estimation technique based on one of the expressions presented in this section.

For cases where single degree of freedom approximations do not give satisfactory answers, the modal parameters can be determined directly by curve fitting either Equation 17 to frequency response information or Equation 24 to unit impulse information. Due to the nonlinear nature of these two equations, the parameter estimation schemes are difficult to implement. In this section several different *multiple degree of freedom* algorithms will be presented.

Frequency Domain Algorithms - The multiple degree of freedom frequency domain algorithms presented are some of the techniques that are currently being developed. The most promising algorithms solve Equation 17 in a least squares sense.

Restating Equation 17:

$$\frac{X_p}{F_q} = -\frac{Y_{pq}}{\omega^2} + Z_{pq}$$

$$+\sum_{r=r_a}^{r_b}\left[\frac{U_{pqr} + jV_{pqr}}{-\delta_r + j(\omega - \omega_{pr})} + \frac{U_{pqr} - jV_{pqr}}{-\delta_r + j(\omega + \omega_{pr})}\right] \tag{25}$$

This equation contains 4n+2 unknown parameters: δr , ω_{dr} , U_{pqr} , V_{pqr} for each of n modes in the frequency range of interest, and two parameters Y_{pq} and Z_{pq} to handle the residual contribution of lower and higher modes. It is obvious

that the equation could be solved given 4n+2 pieces of information, but it would not be wise to do so, because measurement errors would usually cause the solution to be useless. In fact, the equations are nonlinear in δ_r and ω_{dr}, which means that an iterative solution is necessary. Getting a solution of this form to converge to a unique answer in the presence of noise would be very difficult. In order to handle the noise problem, a least squares solution can be used.

Let G represent the experimentally determined frequency response, and H represent the mathematical model Equation 5. The data varies only with frequency, and is known at M frequencies:

$$\left(\frac{Xp}{Fq}\right)_{experimental} = G(f) \qquad f = f_1, f_2, \ldots f_m$$

The model depends not only on frequency, but also on the modal parameters, which will be represented by the 4n+2 components, γ_i, of a vector γ :

$$\left(\overset{Xp}{\frac{Xp}{Fq}}\right)_{model} = H(f, \gamma) = H(f, \gamma 1, \ldots, \gamma 4n+2)$$

The error in the fit at frequency f_k is

$$E_k(\gamma) = G(f_k) - H(f_k, \gamma) \tag{26}$$

and the functional to be minimized for the least squares process is

$$E_t = \sum_{k=1}^{M} E_k(\gamma)\, E_k^*(\gamma) = \sum_{k=1}^{M} \|E_k(\gamma)\|^2 \tag{27}$$

If the derivatives of this error functional with respect to the unkown variables γ_i are set to zero, then there are 4n+2 equations available to determine the unknowns:

$$\sum_{k=1}^{M}\left[E_k^* \frac{\partial H}{\partial \gamma_i}(f_k, \gamma) + E_k \frac{\partial H^*}{\partial \gamma_i}(f_k, \gamma)\right] = 0 \qquad (28)$$

These equations are nonlinear in δ_r and ω_{dr}, and so a solution must be found by an iterative aproximation, starting from initial values for δ_r and ω_{dr}. This means calculating a $\Delta\delta_r$ and $\Delta\omega_{dr}$ for each interaction step. The iteration can be stopped when the process has converged.

Equations 28 can be used in two different ways:

1. A linear least squares method calculating 2n+2 parameters (U_{pqr}, V_{pqr}, Y_{pq}, Z_{pq}), starting with fixed values of δ_r and ω_{dr} that are determined by some other method, and which are constant throughout the solution, or

2. An iterative least squares for all of the modal parameters.

Some details of an algorithm with both solution possibilities are given in Reference 208. This program has been implemented in minicomputer based Fourier analyzers, so that the parameter estimation process can be controlled interactively. If the eigenvalues are not fixed, the solution is best done interactively since the solution will frequently diverge if the starting estimates for the eigenvalues are poorly chosen. The program has a built-in algorithm to recognize a divergent condition and will eliminate the diverging mode and try to continue the solution to convergence using the remaining modes.

Linear Least Squares Algorithm for Residues - If the eigenvalues are known or can be chosen, then the eigenvectors (modal coefficients) can be determined directly, because Equations 28 reduces to a set of linear simultaneous equations. Since the solution is based on a least squares development, the data can be weighted to optimize the results. The type of weighting that should be used depends on the characteristics of the measurement. For example, for very lightly damped data, it is desirable to weight the off-resonance data. The reason for this is that the amplitude is sharply peaked at the resonance, and hence the most significant errors due to "leakage" and nonlinearity will occur at or near the resonances. Data near weak resonances may be more heavily weighted to help extract those modes. Areas of low coherence between input forces and output response should be weighted very lightly.

It is important to include local modes in those measurements where they are active. A local mode is a mode for which the modal displacement is nearly zero at all points on the structure except in a very small region. (The first bending mode of a flagpole on a battleship, for example.)

The least squares modal coefficient calculation is very straightforward and will normally give a solution if a good set of eigenvalues have been determined. The eigenvalues are usually considered to be global properties of the structure, and should therefore be independent of the choice of the measurement point. Variation of the eigenvalues from point to point can be caused by measurement problems or nonlinearities in the structure. On linear structures, the assumption that the eigenvalues are global properties is valid, and this condition can be enforced in the parameter estimation scheme. If the curve fitting process allows

the eigenvalues to change with measurement location, they may vary due to noise, measurement errors, and nonlinearities, and will give confusing results.

It is important, therefore, to be able to obtain a set of global eigenvalues for the structure being analyzed if good modal coefficients are to be estimated using this approach. This normally requires that a good estimate of the number of degrees of freedom be obtained. Also good measurement techniques must be used in order to prevent the eigenvalues from changing as a function of measurement process.

Linearized Least Squares Algorithm for all Modal Parameters - For cases where it is not possible to test the structure so that the eigenvalues remain constant, it is necessary to allow the eigenvalues to change as a function of the measurement position. For example, when a very light structure is tested using transducers with significant mass, the eigenvalues change as the transducers are moved around on the structure, because of mass-loading of the structure. If the eigenvalues are allowed to change, there are 4n+2 unknown parameters in the curve fitting process. From statistical considerations, as the degrees of freedom increase the amount of data that is necessary to obtain the same confidence levels on the estimated parameters likewise increases.

The Gauss-Newton procedure is used to linearize the estimation process. Equation 17 is expanded in terms of a Taylor series, and then the higher-order terms are neglected, using the assumption that the changes in the parameters from their initial (or "starting") values will be small. The result is:

$$H(f,\gamma) = H(f, \gamma_{sv}) + \sum_{i=1}^{4n+2} \frac{\partial H}{\partial \gamma_i}(f, \gamma_{sv}) \Delta\gamma_i \tag{29}$$

where γ_{sv} = vector of starting values of the modal parameters, and $\Delta\gamma_i = \gamma_i - (\gamma_i)_{sv}$ = the change in the i-th parameter.

The error at frequency f_k is now

$$E_k(\gamma) = G(f_k) - H(f_k, \gamma_{sv}) - \sum_{i=1}^{4n+2} \frac{\partial H}{\partial \gamma_i}(f, \gamma_{sv}) \Delta\gamma_i \tag{30}$$

which is linear in all of the parameters γ_i , because γ_{sv} is a constant vector. The derivatives of H with respect to γ_i are created by a formal differentiation of Equation 17, and are evaluated at γ_{sv} . The results are functions of only frequency:

$$\beta_i(f) = \frac{\partial H}{\partial \gamma_i}(f, \gamma_{sv})$$

so the functional to be minimized is

$$E_t = \sum_{k=1}^{M} \| G(f_k) - H(f_{kr}\, \gamma_{sv}) - \sum_{i=1}^{4n+2} \beta_i(f_k) \Delta\gamma_i \|^2 \tag{31}$$

By equating to zero the derivatives of E_t with respect to γ_i, the results are linear equations for the values of $\Delta\gamma_i$. These are solved at each iteration step, and the "starting" values vector is updated,

$$(\gamma_{sv})_{new} = (\gamma_{sv})_{old} + \Delta\gamma \tag{32}$$

in preparation for the next iteration. The iteration is stopped if the least squares error, σ, satisfies the criteria:

$$0.99\sigma_{old} < \sigma_{new} < 1.01\sigma_{old} \tag{33}$$

The iteration procedure is constructed so that any of the eigenvalues can be fixed and the remaining parameters iterated. If any one mode starts to diverge, it can be fixed at the starting value or dropped from the list of eigenvalues. The most common form of divergence is for one mode (which typically has a very small modal coefficient) to start to diverge. If this is allowed to continue, the complete process will diverge.

It is important for the nonlinear solution to have a very good set of starting values and for the data to have minimum distortion due to measurement errors (such as "leakage" errors associated with the Fourier transform (12, 13)).

Time Domain Multiple Degree of Freedom Algorithm - In the time domain the unit impulse response of the viscous-damped linear system is given by Equation 34. Experimentally, the unit impulse can be determined by measuring the frequency response and computing the inverse Fourier transform.

$$h_{pq}(t) = 2\,\mathrm{Re}\left\{ \sum_{r=1}^{n} (U_{pqr} + jV_{pqr}) e^{(\delta_r + j\omega_{dr})t} \right\} \tag{34}$$

In this equation, the unit impulse is described in terms of 4n unknown parameters. The equation is nonlinear in terms of δ_r and ω_{dr} . The Complex Exponential algorithm and the least squares Complex Exponential algorithm can be used to solve for the four parameters of each mode.

Complex Exponential Algorithm - A collocation solution to the parameter estimation problem is developed in Reference 228. The solution technique is referred to as the Complex Exponential algorithm and uses the Prony method of solution. It should be noted that 4n pieces of information are used to determine the 4n unknowns. The equations are nonlinear and an iteration process is used to obtain a solution.

The Complex Exponential algorithm will compute the A_{pqr} and S_r to fit the unit impulse response h_{pq} as given in Equation 34. Since the equation is nonlinear in S_r, the values of S_r are determined by an iterative procedure. The equations are linear in the parameter A_{pqr} , so these coefficients are determined by solving a standard system of linear simultaneous equations.

This algorithm is a collocation parameter estimation technique; there are 4n degrees of freedom, and it uses 4n samples of h_{pq}. In other words, there is no smoothing involved in the estimation process, as there is in a least squares algorithm. Most collocation estimation routines will diverge if the form of the data does not satisfy the assumed model. Due to numerical limitations, the Complex Exponential algorithm tends to compensate for this deviation and will

give a reasonable fit even if it cannot match the underlying form of the actual data. In other words, numerical errors in the calculation prevent the solution from passing exactly through the data points, with the result that the solution process is relatively robust.

When the impulse response function is sampled at equally-spaced instants in time, Equation 34 can be rewritten as:

$$h_{pq}(t_k) = \sum_{r=1}^{N} \left[A_{pqr}\, e^{s_r kT} + A^*_{pqr}\, e^{s^*_r kT} \right] \tag{35}$$

or

$$h_{pq}(t_k) = \sum_{r=1}^{N} \left[A_{pqr} X_r^k + A^*_{pqr} (X^*_r)^k \right] \tag{36}$$

where

N = *number of nodes in the frequency range* (0, 1/2T),

T = sampling interval,

$$X_r = e^{s_r T} \tag{37}$$

Now, h_{pq} is a real valued function; that is:

$$h_{pq}(t_k) = 2\mathrm{Re}\left\{ \sum_{r=1}^{N} A_{pqr} X_r^k \right\} \tag{38}$$

A collocation solution to the set of equations obtained from Equation 38 for different values of t_k can be found using Prony's method. A new set of real-valued unknowns $a_i \; i = {}_0^{2N}$ are introduced which are the coefficients of the terms in the polynomial equation

$$\prod_{r=1}^{N} (X - X_r)(X - X_r^*) = \sum_{k=0}^{2N} a_k X^k = 0 \tag{39}$$

The 2N roots of Equation 39 are the complex exponentials $e^{s_r T}$ and the coefficients a_k are called the autoregression coefficients of the assumed model in Equation 35.

Multiplying Equation 38 by the coefficients a_k and adding the equations (we suppress the subscripts p and q on h and A):

$$\begin{aligned}
a_0 h(t_{m+0}) &= 2a_0 \,\mathrm{Re}\left\{\Sigma A_r X_r^{m+0}\right\} \\
a_1 h(t_{m+1}) &= 2a_1 \,\mathrm{Re}\left\{\Sigma A_r X_r^{m+1}\right\} \\
a_2 h(t_{m+2}) &= 2a_2 \,\mathrm{Re}\left\{\Sigma A_r X_r^{m+2}\right\} \\
&\vdots \\
a_k h(t_{m+k}) &= 2a_k \,\mathrm{Re}\left\{\Sigma A_r X_r^{m+k}\right\} \\
&\vdots \\
a_{2N} h(t_{m+2N}) &= 2a_{2N} \,\mathrm{Re}\left\{\Sigma A_r X_r^{m+2N}\right\} \\
\hline
\sum_{k=0}^{2N} a_k h(t_{m+k}) &= 2\sum_{k=0}^{2N} a_k \mathrm{Re}\left\{\sum_{r=1}^{N} A_r X_r^{m+k}\right\} \\
&= \mathrm{Re}\left\{\sum_{r=1}^{N} A_r X_r^{m} \left(2\sum_{k=0}^{2N} a_k X_r^k\right)\right\}
\end{aligned}$$

According to equation 39, this last term must be zero, so:

$$\sum_{k=0}^{2N} a_k h\,(t_{m+k}) = 0 \quad \text{for } m = 0,1,2,\ldots \tag{40}$$

This equation indicates that there are only 2N linearly independent amplitudes in the sampled impulse response. If the autoregression coefficients are normalized by choosing $a_{2N} = 1$, then

$$\sum_{k=0}^{2N-1} a_k h\,(t_{m+k}) = -\,h(t_{m+2N}) \tag{41}$$

Therefore there are 2N linear equations which can be written for the variables a_k, and these are computed directly from the measured unit impulse response. In practice, the values of m that are used are typically $0 \leq m < 2N$, but any set of 2N can be used. Having solved for the a_k, the roots of Equation 39 can be found using an iterative polynomial solver, and the eigenvalues can be determined from Equation 37.

Once the eigenvalues are determined, the resulting modal coefficients (residue terms) can be calculated from the following relation:

$$\sum_{r=0}^{N} \left[A_{pqr}\, X_r^{\,k} + A^*_{pqr}\left(X_r^*\right)^k\right] = h\left(t_k\right) \tag{42}$$

These equations are linear in the values of A_{pqr}, as in the case of the previous frequency domain solution.

Equations 41 and 42 involve Toeplitz and Van der Monde matrix forms, which can be solved in a much more convenient manner than standard simultaneous linear equation techniques, such as Gauss elimination. Expanding Equation 41 in matrix form (here the typical selections for m are used):

$$\begin{bmatrix} h(t_{2N-1}) & h(t_{2N}) & h(t_{2N+1}) & \dots h(t_{4N-2}) \\ h(t_{2N-2}) & h(t_{2N-1}) & h(t_{2N}) & \dots h(t_{4N-3}) \\ h(t_{2N-3}) & h(t_{2N-2}) & h(t_{2N-1}) & \dots h(t_{4N-4}) \\ \vdots & \vdots & \vdots & \vdots \\ h(t_o) & h(t_1) & h(t_2) & \dots h(t_{2N-1}) \end{bmatrix} \begin{bmatrix} a_o \\ a_1 \\ a_2 \\ \vdots \\ a_{2N-1} \end{bmatrix} = \begin{bmatrix} h(t_{4N-1}) \\ h(t_{4N-2}) \\ h(t_{4N-3}) \\ \vdots \\ h(t_{2N}) \end{bmatrix} \tag{43}$$

Both the Toeplitz coefficient matrix and the constant vector are composed of the unit impulse response. The last row of the coefficient matrix is the initial portion of the unit impulse response. The next to last row is the unit impulse shifted one sampling interval later in time, and so on. As a result of the shifting, the elements of the matrix are identical along any descending-to-the-right diagonal. The Toeplitz matrix solution can be accomplished in computer memory space on the order of N locations versus N squared, and a computation time on the order of N squared versus N cubed, compared to a standard matrix solution.

The Van der Monde matrix equation is derived from Equation 42. In expanded form it is

$$\begin{bmatrix} 1 & 1 & 1 & \dots & 1 \\ X_1 & X_2 & X_3 & \dots & X_N \\ X_1^2 & X_2^2 & X_3^2 & \dots & X_N^2 \\ \vdots & \vdots & \vdots & & \vdots \\ X_1^{N-1} & X_2^{N-1} & X_3^{N-1} & \dots & X_N^{N-1} \end{bmatrix} \begin{bmatrix} A_{pqi} \\ A_{pq2} \\ A_{pq3} \\ \vdots \\ A_{pqN} \end{bmatrix} \begin{bmatrix} h(t_0) \\ h(t_1) \\ h(t_2) \\ \vdots \\ h(t_{N-1}) \end{bmatrix}$$

In this case each row in the matrix is a higher power of the same components as in the previous row. It also can be solved in much less time, with less computer memory, than the general case. The details of the Complex Exponential algorithm can be found in Reference 228.

The Complex Exponential algorithm has the advantage that the nonlinear solution for the eigenvalues is computationally straightforward. Once the eigenvalues have been estimated, the modal coefficients can be directly determined, as was the case with the frequency domain solution. Since it requires no starting values, it is easy to use and is a completely "blind" technique. In order to obtain a solution, it is only necessary to supply the algorithm with the impulse response function and the expected number of modes to be found in the data.

One of the major problems with this technique is that of determining the number of modes in the data. For systems with light damping and widely spaced modes, the most convenient method for estimating the number of modes from the measured frequency response data is by a visual inspection. Of course, data of this type

can be very conveniently analyzed using one of the simpler single degree of freedom techniques. For closely coupled systems with high modal density, it is difficult to estimate the number of degrees of freedom visually. Another complicating factor is that the algorithm needs extra degrees of freedom ("computational" modes) to compensate for noise or distortion in the data. A good rule, based upon experience, is to input one and one-half times the number of modes that are expected.

A second characteristic of the algorithm is that a nonuniform distribution of modes across the frequency range causes the program to miss modes in the areas of high modal density. For this case, it will calculate "computational" modes in areas of low modal density, and not enough modes in the areas of high modal density. If a larger number of modes is specified, the algorithm will eventually find the desired number of modes in the areas of high density, but will compute a large number of "computational" modes. Sometimes it is difficult to separate the real modes from the "computational" modes. The best way to minimize this problem is to use a zoom Fourier transform to measure the frequency response in the regions of high modal density, and then use the Complex Exponential algorithm on the banded frequency response data.

Zoom Fourier transform data can be handled very conveniently with the Complex Exponential algorithm by Fourier-transforming the banded frequency response data into the time domain. The resulting filtered impulse response can be fitted with the Complex Exponential algorithm. In this case the frequencies computed by the algorithm are shifted by the frequency at the beginning of the zoom range (Figure 31). The zoom Fourier transform also helps to reduce distortion errors in the

frequency response measurement due to "leakage", which is a rather significant source of error with the Complex Exponential algorithm.

Mathematically, there is a rather straightforward way to determine the number of modes in a measurement when using the Complex Exponential algorithm. It consists of determining the rank of the coefficient matrix used in calculating the eigenvalues. This can be done by varying the number of potential modes and computing the value of the determinant of the coefficient matrix. Theoretically, when the specified number of modes exceeds the actual number of modes the matrix is singular. If the determinant is evaluated repeatedly for increasing choices of the number of modes, the determinant rapidly falls to zero after the actual number of modes is exceeded. With practical data, noise causes the value of the determinant to decrease gradually, and it typically will never reach exactly zero. Figure 32 shows a schematic diagram of this behavior. It becomes a matter of judgement as to how close the determinant should be to zero. Despite this limitation, the procedure is very useful.

A second method for determining the number of modes involves using different segments of the impulse response to compute the modal coefficients. The variance in the computed modal coefficients can be used to separate the true modes from the "computational" modes.

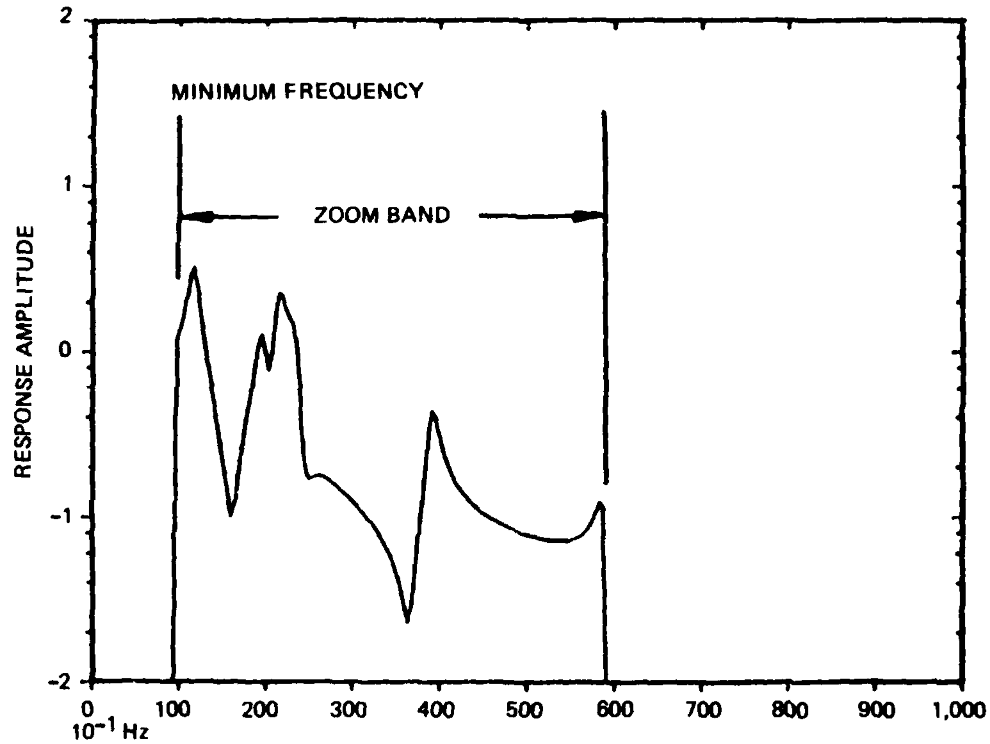


Figure 31. Typical Zoom Frequency Response Measurement

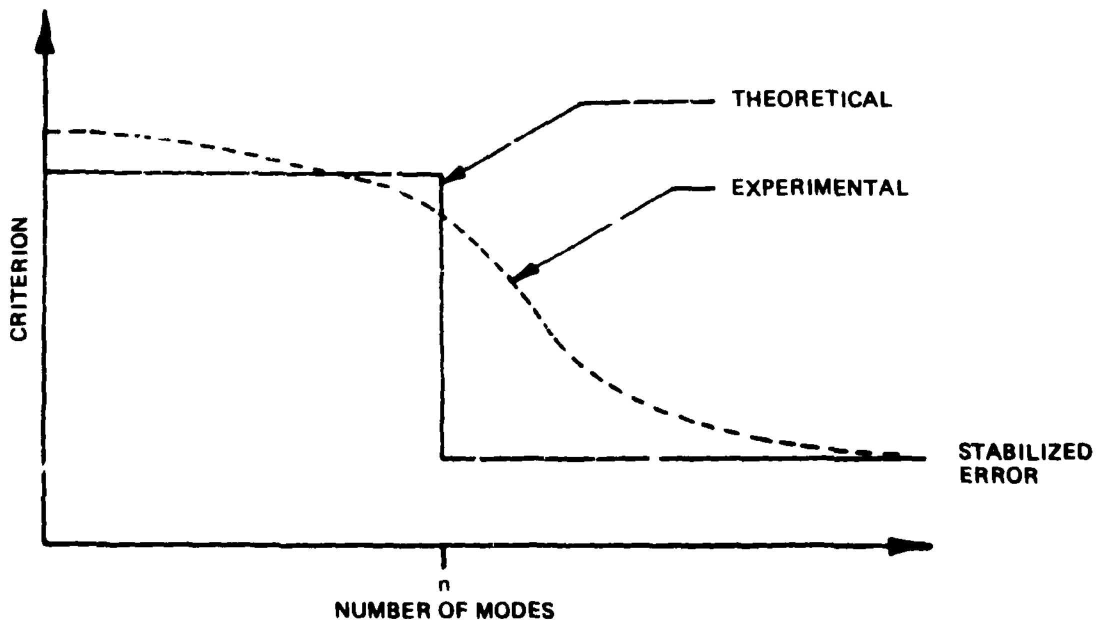


Figure 32. Least Squares Multiple Degree of Freedom Criterion

A significant source of error concerning the use of the Complex Exponential algorithm is the truncation of the frequency response in the frequency domain. A sin(x)/x type of distortion error is induced in the corresponding impulse response. This results in distorted estimates for damping and frequency (Figure 33).

The greatest problem with using the Complex Exponential algorithm for modal parameter estimation is that a new set of eigenvalues is computed for every measurement, when in theory, the eigenvalues are global properties of the structure. It should be noted that for any given measurement there are a number of sets of eigenvalues which can be computed by the Complex Exponential algorithm, depending on the number of degrees of freedom allowed. Any one of these sets will fit the data to within very close limits. From a plot of the curve fit data, it may not be possible to distinguish any difference. The resultant set of data that will be computed depends on small differences in the measured data due to noise or distortion. The variation between the computed modal coefficients can easily exceed 30%, while the fit to the frequency response may be within 1%. An example of this is shown in Figure 34.

In summary, the Complex Exponential algorithm is a very simple technique to use. It does an exceptional job of fitting any individual measurement, but because it can compute different eignevalues for each measurement, it has limited applicability for modal measurements. It is also rather sensitive to noise since it has no inherent smoothing. For single measurements it works very well, so it appears to be generally useful for single-input and single-output systems.

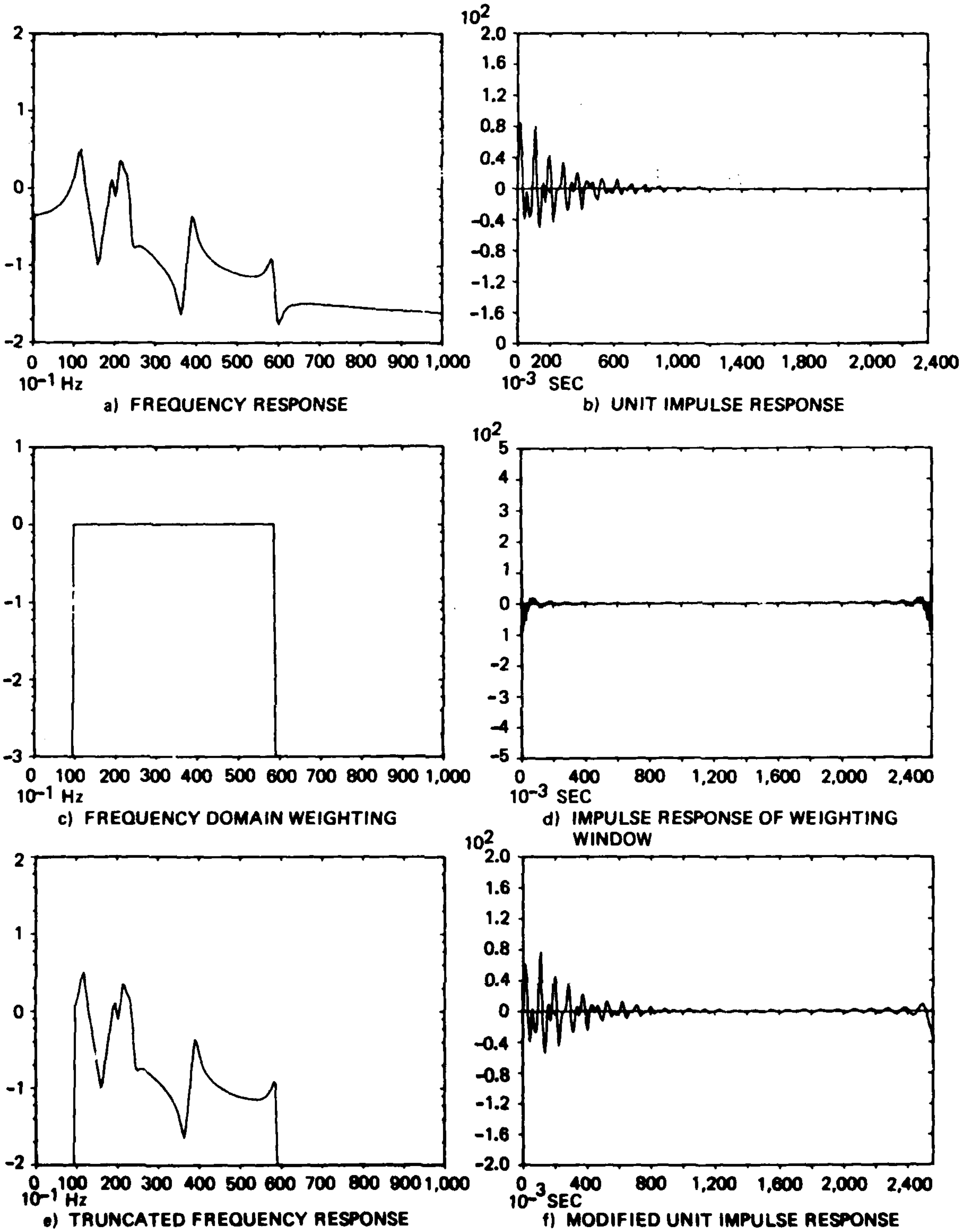
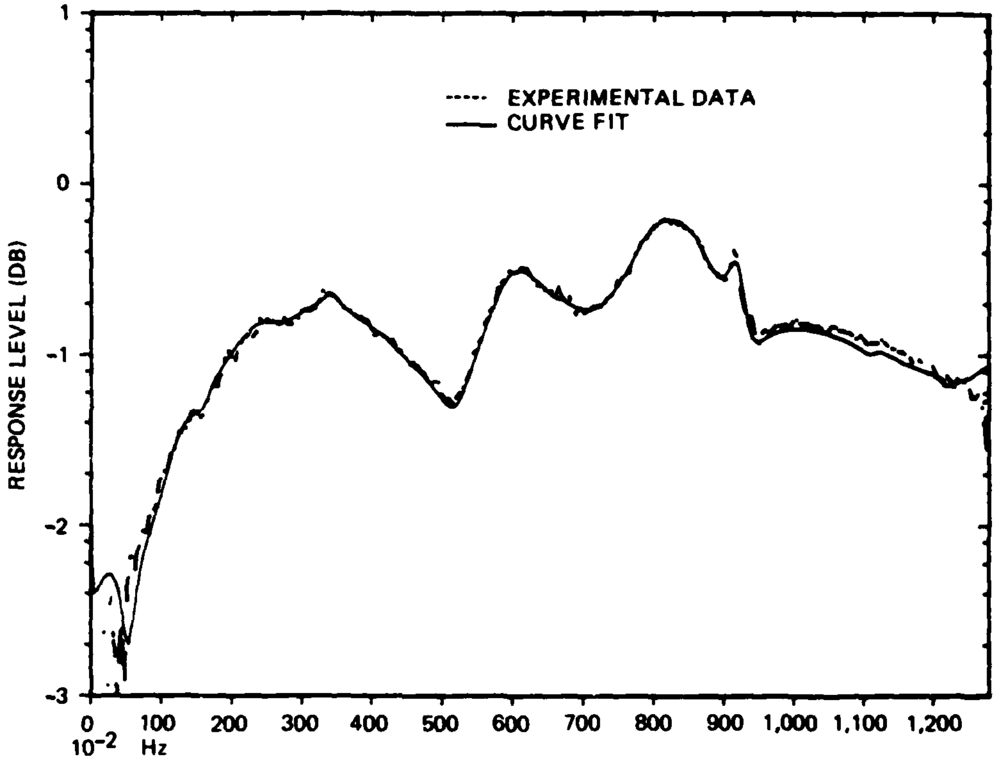
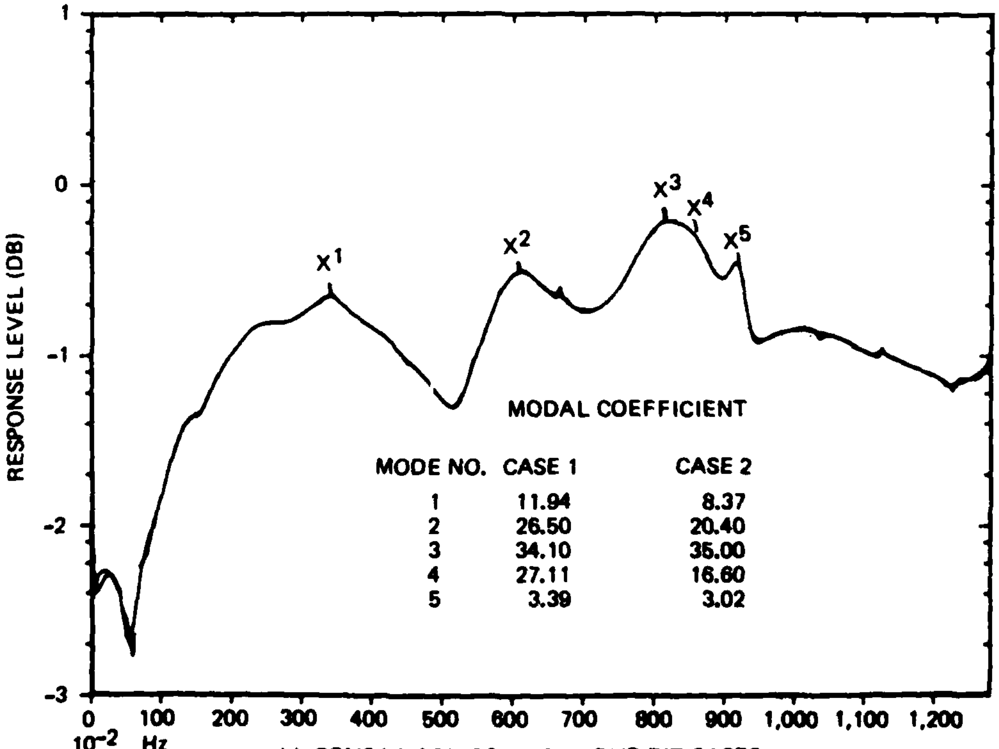


Figure 33. Use of the Complex Exponential Algorithm



a) COMPARISON OF EXPERIMENTAL DATA AND CURVE FIT DATA



b) COMPARISON OF TWO CURVE FIT CASES

Figure 34. Curve Fitting Comparison Using the Complex Exponential Algorithm

Least Squares Complex Exponential Algorithm - The Prony algorithm used in the Complex Exponential Algorithm can be replaced by a least squares method. As usual, we write the sum of the squares of the errors, differentiate with respect to the parameters, and set the result to zero, in order to find the values of the parameters which minimize the sum. From Equation 41, the error in the fit for the m-th equation is:

$$E_m^2 = [\sum_{K=0}^{2N-1} a_k h(t_{m+k}) + h(t_{m+2N})]^2 \tag{44}$$

and thus the total error is

$$E = \sum_{m=1}^{M} E_m^2 \tag{45}$$

where M is the number of equations that are used in the fit. The derivatives are given by

$$\frac{\partial E}{\partial a_i} = 0 = \sum_{m=1}^{M} h(t_{mti}) [\sum_{k=0}^{2N-1} a_k h(t_{m+k}) + h(t_{m+2N})] \tag{46}$$

or

$$\sum_{k=0}^{2N-1} a_k [\sum_{m=1}^{M} h(t_{m+i}) h(t_{m+k})] + \sum_{m=1}^{M} h(t_{m+i}) h(t_{m+2N}) = 0 \tag{47}$$

Making the substitution

$$R_{i,k} = \sum_{m=1}^{M} h(t_{m+i}) h(t_{m+k}) \tag{48}$$

the resulting equations are

$$\sum_{k=0}^{2N-1} R_{i,k} a_k = -R_{i,2N} \tag{49}$$

or in matrix form,

$$\begin{bmatrix} R_{0,0} & R_{0,1} & R_{0,2} & \cdots & R_{0,2N-1} \\ R_{1,0} & R_{1,1} & R_{1,2} & \cdots & R_{1,2N-1} \\ R_{2,0} & R_{2,1} & R_{2,2} & \cdots & R_{2,2N-1} \\ \vdots & \vdots & \vdots & & \vdots \\ R_{2N-1,0} & R_{2N-1,1} & R_{2N-1,2} & \cdots & R_{2N-1,2N-1} \end{bmatrix} \begin{bmatrix} a_0 \\ a_1 \\ a_2 \\ \vdots \\ a_{2N-1} \end{bmatrix} = - \begin{bmatrix} R_{0,2N} \\ R_{1,2N} \\ R_{2,2N} \\ \vdots \\ R_{2N-1,2N} \end{bmatrix} \tag{50}$$

When M becomes very large, the values of $R_{i,k}$ are approximately equal to the values of the autocorrelation function R_{hh} (i-k). Here the lag value (i-k) is the true lag value divided by the sampling interval, T. Because the autocorrelation function is even, that is,

$$R_{hh}(i-k) = R_{hh}(k-i) \tag{51}$$

the equations can be expressed in terms of the autocorrelation function as

$$\begin{bmatrix} R_{hh}(0) & R_{hh}(1) & R_{hh}(2) & \cdots & R_{hh}(2N-1) \\ R_{hh}(1) & R_{hh}(0) & R_{hh}(1) & \cdots & R_{hh}(2N-2) \\ R_{hh}(2) & R_{hh}(1) & R_{hh}(0) & \cdots & R_{hh}(2N-3) \\ \vdots & \vdots & \vdots & & \vdots \\ R(2N-1) & R(2N-2) & R(2N-3) & \cdots & R_{hh}(0) \end{bmatrix} \begin{bmatrix} a_0 \\ a_1 \\ a_2 \\ \vdots \\ a_{2N-1} \end{bmatrix} = - \begin{bmatrix} R_{hh}(2N) \\ R_{hh}(2N-1) \\ R_{hh}(2N-2) \\ \vdots \\ R_{hh}(1) \end{bmatrix} \tag{52}$$

The least squares residues (modal coefficients) can be computed from the unit impulse response as follows. From Equation 42, the unit impulse response can be written in terms of sine and cosine functions. Assuming that the mean value of h_{pq} is zero.

$$h_{pq}(t_k) = 2 \sum_{r=1}^{N} e^{\delta_r t_k} [U_{pqr} \cos(\omega_{pr} t_k) + V_{pqr} \sin(\omega_{pr} t_k)] \tag{53}$$

The error in the fit to the k-th point of the impulse response is chosen as the discrepancy between this model and the data, g_k , for k=0,1,2,...,M:

$$E_k = g_k - h_{pq}(t_k) \tag{54}$$

and the total error functional associated with the fit of M samples is

$$E = \sum_{k=1}^{M} [g_k - \sum_{r=1}^{N} (C_{rk} U_{pqr} - S_{rk} V_{pqr})]^2 \tag{55}$$

where the notation $C_{ik} = e^{\delta_i t_k} \cos(\omega_{di} t_k)$ $S_{ik} = e^{\delta_i t_k} \sin(\omega_{di} t_k)$
was used

$$\frac{\partial E}{\partial U_{pqi}} = \sum_{k=1}^{M} C_{ik} [g_k -2 \sum_{r=1}^{N} (C_{rk} U_{pqr} - S_{rk} V_{pqr})] \tag{56a}$$

$$\frac{\partial E}{\partial V_{pqi}} = \sum_{k=1}^{M} S_{ik} [g_k -2 \sum_{r=1}^{N} (C_{rk} U_{pqr} - S_{rk} V_{pqr})] \tag{56b}$$

Let

$$A_{ir} = \sum_{k=1}^{M} C_{ik} C_{rk} \qquad B_{ir} = \sum_{k=1}^{M} S_{ik} S_{rk}$$

$$D_{ir} = -\sum_{k=1}^{M} C_{ik} S_{rk} \qquad X_i = \sum_{k=1}^{M} C_{ik}\, g_k$$

$$Y_i = -\sum_{k=1}^{M} S_{ik}\, g_k \qquad U_i = U_{pqi}\; V_i = V_{pqi}$$

Then the matrix form of the equations for the residues is

$$\begin{bmatrix} A & D \\ D^T & B \end{bmatrix} \begin{bmatrix} U \\ V \end{bmatrix} = \begin{bmatrix} X \\ Y \end{bmatrix} \tag{57}$$

where A, B, and D are N x N submatrices, U_{pq} , V_{pq} , X, and Y are N x 1 column vectors, and D^T is the transpose of D. The formal solution for the real and imaginary components of the modal coefficients is

$$\begin{bmatrix} U \\ V \end{bmatrix} = \begin{bmatrix} A & D \\ D^T & B \end{bmatrix}^{-1} \begin{bmatrix} X \\ Y \end{bmatrix} \tag{58}$$

There is an approximate solution

$$U_{pqr} = X_r / A_{rr} \qquad V_{pqr} = Y_r / B_{rr} \tag{59 a,b}$$

which is valid when the diagonal terms, compared to the off-diagonal terms, are very large in the coefficient matrices A and B, and the elements of D are small.

The major advantage of the least squares version of the Complex Exponential algorithm is that it has least squares elimination of noise. Like all least squares techniques the data can be weighted so that the parameter estimation will favor the strongly weighted data. For cases where the testing procedures generate eigenvalues which can be considered global properties of the structure, this algorithm can be used to determine a weighted least squares estimate of the eigenvalues. All of the measurements can be used, or any selected combination of measurements. It can be used to determine overall system modes, or it can be used on any subset of the measurements to estimate local modes.

The least squares version of the Complex Exponential algorithm has the same problems as the ordinary Complex Exponential algorithm. It is difficult to estimate the number of modes to input into the algorithm. Again the rank of the matrix given in Equation 50 can be used to estimate the number of independent modes in the data, as can the least squares error function. The least squares error is large when too few modes are assumed in the solution, and reduces to some small value determined by the numerical noise when too many modes are assumed. A schematic plot of the error as a function of the number of assumed modes is shown in Figure 32. As can be seen from this figure, for actual data the curve gradually approaches the noise floor, and it is a judgement to specify the optimum number of modes. In Figure 35 the least squares error is shown as a function of the number of assumed modes for a typical structure.

```
DOF  2  ERROR =   .131646E+00 @**********************************     @
DOF  3  ERROR =   .849838E-01 @**********************************     @
DOF  4  ERROR =   .637487E-01 @*********************************      @
DOF  5  ERROR =   .381210E-01 @********************************       @
DOF  6  ERROR =   .333203E-01 @********************************       @
DOF  7  ERROR =   .206978E-01 @*******************************        @
DOF  8  ERROR =   .136885E-01 @*******************************        @
DOF  9  ERROR =   .586078E-02 @*****************************          @
DOF 10  ERROR =   .457281E-02 @*****************************          @
DOF 11  ERROR =   .264529E-02 @****************************           @
DOF 12  ERROR =   .203324E-02 @***************************            @
DOF 13  ERROR =   .629060E-03 @*************************              @
DOF 14  ERROR =   .345465E-03 @************************               @
DOF 15  ERROR =   .318746E-03 @************************               @
DOF 16  ERROR =   .291623E-03 @************************               @
DOF 17  ERROR =   .246767E-03 @************************               @
DOF 18  ERROR =   .184763E-03 @***********************                @
DOF 19  ERROR =   .184928E-03 @***********************                @
DOF 20  ERROR =   .157361E-03 @***********************                @
DOF 21  ERROR =   .146148E-03 @***********************                @
DOF 22  ERROR =   .144245E-03 @***********************                @
DOF 23  ERROR =   .132823E-03 @**********************                 @
DOF 24  ERROR =   .991931E-04 @**********************                 @
DOF 25  ERROR =   .716190E-04 @*********************                  @
DOF 26  ERROR =   .642475E-04 @*********************                  @
DOF 27  ERROR =   .555702E-04 @*********************                  @
DOF 28  ERROR =   .512450E-04 @*********************                  @
DOF 29  ERROR =   .425030E-04 @*********************                  @
DOF 30  ERROR =   .427652E-04 @*********************                  @
DOF 31  ERROR =   .485362E-04 @*********************                  @
DOF 32  ERROR =   .434270E-04 @*********************                  @
DOF 33  ERROR =   .411622E-04 @********************                   @
DOF 34  ERROR =   .274866E-04 @********************                   @
DOF 35  ERROR =   .258191E-04 @********************                   @
```

Figure 35. Error Output From Algorithm

In general, the least squares version of the Complex Exponential algorithm does a very good job of generating a set of eigenvalues for a structure. For a given choice of input location (exciter position) a set of eigenvalues will be generated which will do an excellent job of fitting all of the measurements taken with the exciter position. A different exciter position may generate a different set of eigenvalues and eigenvectors. At the present time an engineers judgement is required to edit the sets of eigenvectors generated from different exciter positions into a consistent set which can be used to describe the structural characteristics of the system being analyzed.

Mode Enhancement

Enhancement of one mode in a frequency range may be accomplished by a technique that is based on the same principle as the generation of normal modes for the multiple-exciter sine test. A forced-response function is created by computing a linear combination of a set of frequency response functions that have either a common response location or a common exciter location. The coefficients of this linear combination correspond to a forcing vector applied to the structure at the varying locations associated with the set of frequency response functions used. If the variation is in the exciter location, this correspondence is direct; if the variation is in the response locations, then the correspondence depends on the validity of assuming that the structure has a symmetric frequency response function matrix (that is, that Maxwell-Betti reciprocity is true for the structure).

When the vector composed of the coefficients of the linear combination (the pseudo-forcing vector) is approximately equal to the components of the mode shape for the mode to be enhanced, the mode of interest is "excited" more strongly than the other modes, and the forced-response function appears much more like a frequency response function of a structure having a single degree of freedom.

Figure 36 shows a typical measurement from a test executed under adverse conditions for measurement of frequency response. Figure 37 shows a forced-response function derived from a set of measurements from that test that enhances one of the modes seen in Figure 36.

For a proper choice of the pseudo-forcing vector, the forced-response function can be used with a curve fitting program to obtain a better determination of a mode's eigenvalue than would be calculated from any of the frequency response functions used in the linear combination. If there are frequency response measurements available for several exciter locations as well as several response locations, then a set of forced-response functions can be computed, using the same pseudo-forcing vector, to calculate mode shape components with greater accuracy.

This enhancement technique requires that the frequency response functions in the linear combination be consistent, in the sense that they all have the same eigenvalue for the mode to be enhanced, and that the pseudo-forcing vector correspond rather closely to the mode shape. If this is not the case, the forced-response function will include distortions that prevent the curve fitting programs from computing a proper eigenvalue. In fact, executing the enhancement

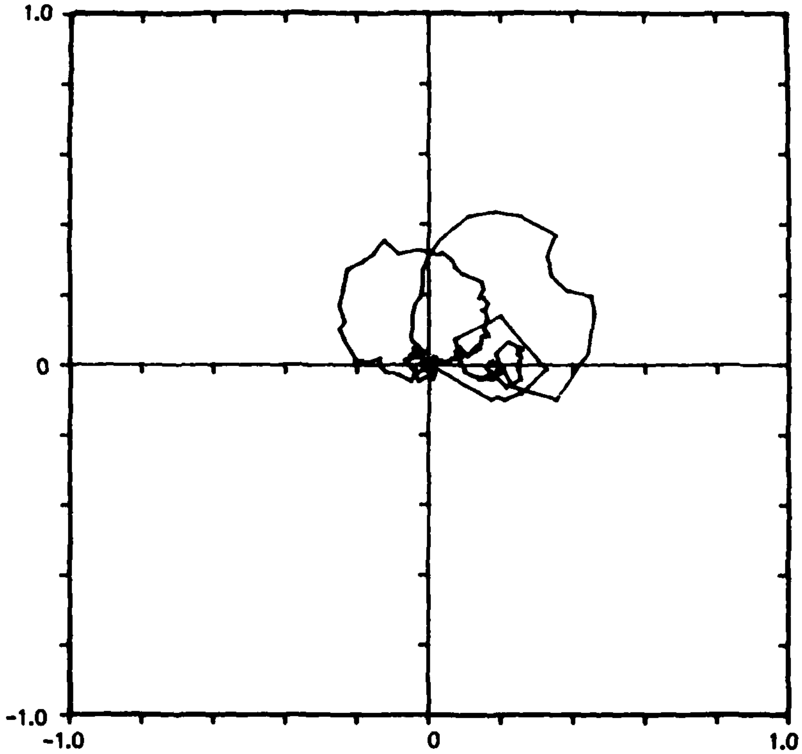


Figure 36. Argand Plane—Typical Measurement

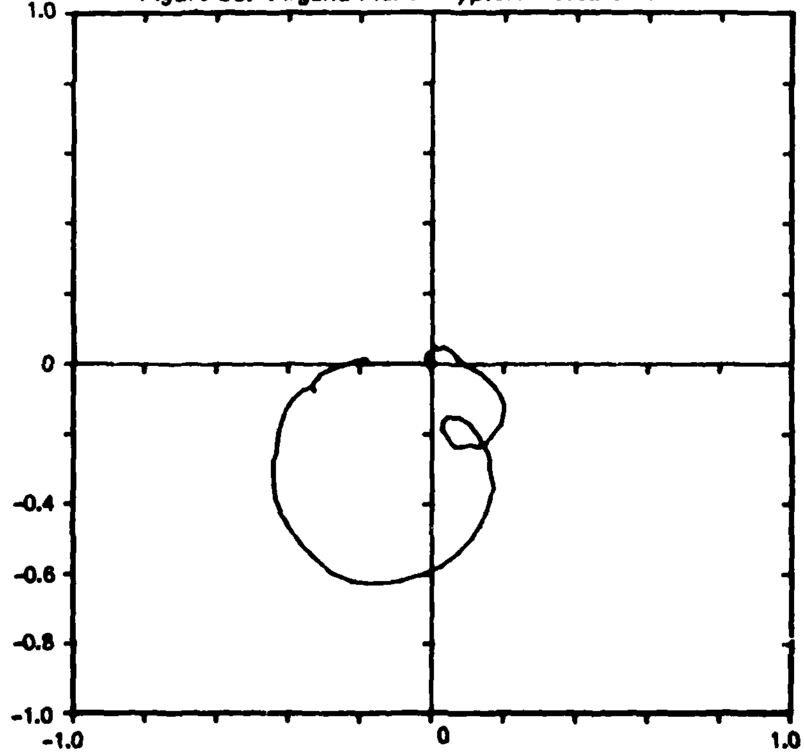


Figure 37. Argand Plane—Enhanced Measurement

and curve fitting the result provides a check on the validity of the eigenvalue and eigenvector that were obtained directly from the frequency response functions.

For the example shown in Figure 34, the quadrature response was used to generate the pseudo-forcing vector.

3.1.2.3 Mathematical Model Correlation

Correlation between ground vibration test results and mathematical models is meaningful only in the areas of significance of the mathematical model. This applies not only to bandwidth, but also to the area of the airplane under consideration. For example, in a mathematical model for flutter analysis the frequency range of interest on the wing may be 5-15 Hz, that on the vertical tail 10-30 Hz, that on a control surface 40-100Hz and that on a control surface tab 100-200 Hz.

Mathematical Model Comparisons

Mode Shape and Frequency - The most common comparison is on modeshape and frequency. The modeshapes and natural frequencies of the mathematical model are computed. Usually the mathematical model is the free-free airplane; occasionally the free-free model is modified to include the GVT boundary conditions. Generally, unless both frequency and modeshape are quite close the correlation is deemed poor. Poor correlation could be due to errors in mathematical modeling, measurement or modal interpretation of the measurement.

Frequency Response Function - Occasionally frequency response functions of the mathematical model with the GVT boundary conditions are computed. In the comparison of measured with calculated frequency response functions, no modal analysis of the measurement, involving the judgment of the test engineer, is involved. It has the disadvantage that the analysis engineer must make assumptions about damping in his analysis. In this comparison the frequency of significant response peaks and their relative amplitudes must agree well or the comparison is poor. In this case poor correlation is due to errors in mathematical modeling or measurement.

Mathematical Model Revisions

Intuitively Based - Revisions of mathematical models to match test results is nearly always intuitively based. This is an art all of its own, and discussion of it is beyond this report.

Systems Identification - Although considerable research has been expended in identifying point mass, stiffness and damping from GVT data, little of this research has reached application. The principle difficulties seem to be involved with reliability and with handling noise contaminated test data. Work remains to be done in developing rugged, useful systems identification algorithms.

4.0 CONCLUSIONS

4.1 STATE OF THE ART

Recent advances in vibration testing have made it possible to use substantially fewer resources to conduct tests of the same or higher quality than previously. Typically, the application of these advances can reduce cost, reduce time on test, and reduce the number of people involved. The improvements include using computers, improved test equipment, digital systems and developments in vibration testing theory.

Application of the minicomputer to the vibration test has provided the most stunning advance. The minicomputer has made possible automating excitation and data acquisition, data management and on-site or off-line frequency response analysis.

Test equipment has benefited from the recent advances in electronic circuitry design as well as routine design improvements. LSI chips and microprocessors have found application throughout the test systems giving inexpensive, high sensitivity, rugged transducers, and modest cost autoranging amplifiers, analogue to digital and digital to analogue converters, multiplexers and other items. Mechanical design improvements have included readily available off the shelf suspension system components.

Converting the signal format to digital throughout much of the test equipment system has substantially improved dynamic range, improved signal to noise levels and has often reduced equipment cost.

Vibration testing theory advanced when the application of the digital computer and frequency response analysis to vibration testing made practical many concepts heretofore only of academic interest. Vibration testing theory has developed by adapting and expanding upon Fourier Analysis, digital signal processing theory and the theory of random processes.

4.2 RECOMMENDED GVT METHOD

Single Point Excitation/Frequency Response Analysis Method

The recommended method for ground vibration testing is the single point excitation/frequency response analysis methods. Its primary advantages over other methods are that it is more efficient and has the prospect for substantial improvement. In particular, the multipoint excitation/sine dwell method has had many years development and should be considered mature, yet both it and the recommended method give equivalent results. Also, the test time and cost estimates for the recommended method are reliable whereas good estimating of test time and cost for the multipoint excitation/sine dwell method is often quite difficult because of the unpredictability of the effort required in tuning each mode.

5.0 RECOMMENDATIONS

5.1 GROUND VIBRATION TEST METHOD

The recommended ground vibration test method is the single point excitation/frequency response analysis method. The recommended method is directly applicable as described to whole airplane ground vibration tests. For testing models and components the recommended method, with appropriate adaptations for test article support and size, is applicable. Although the recommended method is currently in use for flight flutter testing, and gives results equally satisfactory to those from other methods, improvement on current practice is needed. Specifically, signal to noise ratios are often poor, particularly when flying in turbulence, and rapid reliable techniques for estimating damping are lacking.

5.2 EQUIPMENT

5.2.1 Digital

The entire signal handling system used in the test should be based on digital equipment to as near to the data capturing sensors as possible. The advantages of going digital are many. Signal quality deterioration downstream of the analogue to digital converter is virtually eliminated, digitally based equipment has become very reasonably priced and computer compatibility of the system is enhanced.

5.2.2 Multiplexer

The multiplexer converts a number of parallel data streams from the transducers into one time division multiplexed signal. It makes possible recording the digital output from a large number of transducers serially on tape or disk. Using a multiplexer is desirable because it substantially increases the efficiency of the data recording system.

5.2.3 Autoranging Amplifier

An autoranging amplifier should be used. A variable gain amplifier is necessary on each signal circuit. Using a piece of hardware which sets its own gains makes the process much more reliable by eliminating a possibility for human error, reduces test time by speeding up the gain setting process and reduces the size of the test crew.

Although autoranging type amplifiers have been available for a long time, recent advances in electronics have resulted in price reductions that have made their use in a GVT practical.

5.2.4 Soft Support System

The use of a soft support system is recommended. In the past soft support systems tended to be costly, difficult to keep functioning well and generally not too successful. The advent of commercial airsprings has changed this. The commercially available airsprings with a servo controlled level and integral damping satisfy the isolation requirements at modest cost.

5.2.5 FFT Computer

The minicomputer incorporating fast Fourier transform capability is an essential item of equipment for testing via the single point excitation/frequency response analysis method. The use of the FFT computer has become practical with the reductions in price for the computer and with the development of software for use on the GVT.

5.3 FURTHER RESEARCH AND DEVELOPMENT

5.3.1 Measures of Confidence

5.3.1.1 Measurement

Currently the quality of the measurements is observed by monitoring the raw signals for all channels on oscilloscopes and by computing frequency response and coherence functions for the reference accelerometer. Although the frequency response and coherence functions are fine measures of measurement quality, they are usually available for only one channel of data. It would be impractical to compute and monitor these functions for all channels. A better approach is needed.

5.3.1.2 Analysis

The modal confidence factor and the modal assurance criteria are fine aids in estimating the quality of curve fit modes. Further work is needed in developing

methods which can compare a set of curve fit modes with all the frequency response functions from all the excitation points of a test. These methods will probably have to be statistical in nature.

5.3.2 Mathematical Model Correlation Criteria

Current techniques for comparing the test results with a mathematical model are clearly unsatisfactory.

The usual approaches are to compare curve fit modeshapes and frequencies with modeshapes and frequencies computed from the mathematical model. The difficulty comes in accessing the significance of differences between the test and analysis results. E.g., is a 5% difference in second torsion mode natural frequency acceptable? Is 10%? Is 20%?

Two approaches to improve mathematical model correlation seem evident. The first is to base the correlation on frequency response function, not on modeshapes and frequencies. This avoids the most subjective part of the test. The second is that a specific correlation exercise has significance only in terms of the application area intended for the mathematical model. This probably implies a weighting function applied to an error function. An end product of an approach like this could be a rating of the correlation error in terms of the performance criteria involved. An expected result of a correlation exercise like this might be:

Application Area	Correlation Error
Low Altitude Flutter	20 Knots Flutter Speed
High Altitude Flutter	-40 Knots Flutter Speed
Low Speed, Low Altitude Gust	10% Wing Root Bending Moment
Bomb Damage Repair Induced Taxi Loads	-15% Pylon Loads

5.3.3 Curve Fitting Algorithms

5.3.3.1 Algorithm Development

Current curve fitting algorithms require substantial operator intervention and expend much operator time on routine tasks. In addition to automating the routine curve fitting tasks, algorithms are needed which are more noise tolerant, which utilize simultaneously data from several single point excitation runs and which are more efficient. Work is also needed in systems integration of algorithms so that on one computer system, without reformatting the stored data, the engineer could call up any algorithm for use. There are a number of approaches which, although referred to as independent methods, are really only alternative curve fitting algorithms. One such algorithm is Ibrahims Time Domain Method. These algorithms should be incorporated into an integrated system.

5.3.3.2 Computer Systems

Most algorithm development has been done on minicomputers. Some of the new algorithm developments are near the capacity of these machines. New algorithm development should follow two paths. In the future all algorithms that need

large computer capacity should be developed for use on big mainframe computers. All algorithms, large or small, should be installed on the big mainframe computer. The large and small systems should be as compatible as possible so that a set of test results may be processed on both systems as necessary.

5.3.4 System Identification

Development of the point mass, stiffness and damping of a structure from test modeshape, frequency and damping has been pursued for many years. These approaches involve nonlinear systems of equations, and are difficult. The success of these approaches has been limited. An alternative approach is suggested for development work. Beginning with the measured frequency response function, algorithms should be developed which best fit unknown values for point mass, stiffness and damping in a mathematical model. This has the advantages that:

1. This approach is linear, insuring a much greater chance of success than nonlinear approaches and
2. The engineer may specify portions of his mathematical model as known and other parts as variables to be best fit. This has the advantage of minimizing the size of the problem and of reflecting the reality that the engineer usually has portions of the mathematical model he is quite confident are correct and parts where he doubts the correctness of the model. The engineer usually knows where the problem areas are.

5.3.5 Instrumented Test Boundary Condition

In principle, no special boundary condition is necessary for a ground vibration test. If the forces and accelerations are measured across the boundaries, the frequency response function for the free-free test article may be computed from the measured frequency response functions. There would be much advantage in eliminating the requirements for a special boundary condition. A three part investigation is suggested.

1. Computer studies. Exercise the equations with noise contaminated signals and with various kinds of boundary conditions.
2. Laboratory model studies. Repeat the exercises of 1. on laboratory models.
3. Airframe GVT. Get an old airframe out of the boneyard and experiment with various excitation signals, boundary conditions, etc.

5.3.6 Data Basing Systems

Large volumes of data are created in a ground vibration test. Data basing systems should be applied to the storage and retrieval of this data.

5.3.7 Utility Computer Programs

The family of utility computer programs for use on minicomputer based modal analyzers is inadequate. Engineers using these computers waste considerable time executing the steps in utility tasks manually. The utility computer programs to automate these tasks should be written.

5.4 APPLYING GVT IMPROVEMENTS

5.4.1 Documentation

Improvements are needed in the cost and quality of contractor ground vibration tests without increasing total program cost. It is suggested that this could be accomplished by requiring that the usual intermediate steps of the process be formally documented (rather than informal internal documentation as is usual). Quality is invariably enhanced when data is prepared for Company management review prior to release. However, since this data is normally prepared anyway, the total program cost increase should be minimal.

5.4.2 Pretest Analysis

The pretest analysis predicts the frequency response functions that will be measured in the test. The mathematical model of the airplane plus the mathematical model of the support system is used in this computation. This pretest analysis is an important aid in test planning. The pretest analysis should be completed before proceeding with the ground vibration test.

5.4.3 Frequency Response Function

The frequency response function is the direct result of the test measurement, normalized to unit force levels. The development of the frequency response function is direct and straight-forward, following very routine procedures.

The frequency response functions should be part of the GVT test report. This should include the coherence functions associated with the frequency response functions.

5.4.4 Correlation With Mathematical Model

Correlation with the mathematical model should be a required part of the test report. At present this correlation would be limited to comparing modeshapes and frequency. As the correlation criteria of section 5.3.2 are developed they should be applied to give a more definative measure of the differences between the mathematical model and the test.

5.4.5 Soft Support Measurement

If a soft support is used, the bandwidth on selected frequency response functions must include the soft support frequencies. A sufficient number of excitation locations and response points must be included so that all the rigid body airplane on soft support modes are measured.

5.4.6 Modal Characteristics

The modeshapes, natural frequencies and dampings deduced from the test should be included in the GVT test report, just as is done at the present.

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APPENDIX A

GUIDE FOR GROUND VIBRATION

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APPENDIX A

GUIDE FOR GROUND VIBRATION TESTING OF AIRPLANES

1.0 INTRODUCTION

This "Guide for Ground Vibration Testing of Airplanes" contains guidelines for ground vibration testing via the single point excitation/frequency response analysis method. It is intended that these guidelines not be dogmatic; the state of the art is changing rapidly, the engineering philosophy in various organizations will dictate many different approaches to problems and the equipment and skilled manpower available will circumscribe one's capabilities.

The approach taken here is that of an aircraft manufacturer. It is assumed that costs involved in the test are weighed on a return on investment basis. The consequences of this are that testing time must be minimized, cost and manpower expenditures controlled and computerized equipment agressively utilized.

This guide discusses test planning, test equipment, test operations, and general guidelines, both as they apply to ground vibration testing in general, and to the single point excitation/frequency response analysis method in particular.

2.0 TEST PLANNING

2.1 Test Planning Document

The principal written coordination vehicle between the customer for the test and the testing group is the test planning document. It must encompass all aspects of the test and documentation of the test. The document is written jointly by the customer engineer responsible for the test and the test group engineer responsible for the test. This document is revised many times, as often as necessary, to keep it up to date with current plans as the test date approaches. Since all people involved with conducting the test receive copies of the test plan document, the regular revisions help keep everyone current.

2.2 Test Schedule

Pre-test planning should include a carefully layed out test schedule for both equipment and manpower allotments. The airplane preparation should be planned and sufficient time allotted for each item. Instrumentation that is required must be planned for and made ready for the test.

2.2.1 Boilerplate Tests

Frequently test equipment is to be used or test procedures used which are new. The risk of problems with untried equipment or new procedures during the ground vibration test is minimized by conducting boilerplate tests with them before the GVT. The boilerplate tests are conducted in the laboratory some time before the GVT. They are conducted on an ad hoc basis with minimum crew and expenditure.

2.2.2 Length of Test

Since most airplanes are essentially ready for flight at the time of a GVT, the time available for the test is usually at a premium. The new techniques used for GVT have vastly reduced the length of tests and have resulted in efficient automation of data. Since several vibrator locations are usually used with different airplane configuration, the time for test will vary.

For a new airplane configuration where a complete GVT is required, a carefully planned test will require from eight to twelve, eight-hour shifts.

2.2.3 Test Crew

The required test crew for a GVT will vary according to the complexity and amount of data points that are required. Normally, for a large airplane, the crew will consist of:

Set-up crew to move equipment into place

Instrumentation crew to place transducers, string cable, hook-up all electronic equipment, perform calibration and operate equipment.

Test planners, director, and supervision.

The total manpower requirement varies from 3 to 20 persons, depending on the complexity of the test, the latter being an all up test on a large airplane running three shifts a day until completion.

2.3 Test Planning for Measurement Phase

2.3.1 Equipment List

A complete and comprehensive equipment list must be prepared at the earliest possible date. It should contain a list of the equipment that will be required for the test, including transducers, cables for transducers and vibrator, amplifiers, filters, tape recorders, oscillographs, VTVM, oscilloscope, function generator, computer equipment, etc.

2.3.2 Airplane Configuration

A detailed description of the configuration(s) that are to be tested should be drawn up. Control surface support, weight of equipment, and landing gear configuration must be spelled out in detail. The testing sequence must be planned so that reconfiguration of the airplane for successive test conditions is performed as efficiently as possible.

2.3.3 Airplane Suspension

Since the method of suspension may affect the test data, detailed planning must be done for exact configuration of suspension system. Plans should be made to check support frequencies and damping of the airplane suspension system.

2.3.4 Accelerometer Locations

A drawing should be prepared of complete airplane calling out exact body station and water line of each accelerometer. Lists should then be made and tabulated for the test document describing the location of the measured structural response locations.

2.3.5 Exciter Locations

A pretest analysis can be used to determine the best location(s) to excite the modes. Usually several locations will be used. Each location should be clearly indicated on pre-test plan drawings or sketches with WL and BS called out.

2.3.6 Pre-Test Analysis

A pre-test analysis of the airplane to be tested is desirable. A pre-test anslysis uses a mathematical model of the airplane structure. This mathematical model may be a finite element model, a beam model or some other abstraction of the airplane structure. The most desirable math model is the airplane in GVT configuration, including the test boundary conditions at the airplane support. Less desirable are models of the free-free airplane or the airplane in configurations similar to the test configuration. Models of the airplane in other configurations are of lesser value.

There are two kinds of pre-test analysis. The first is computation of frequency response functions. This calculation of the response at various points in the

structure due to excitation at a point, as a function of excitation frequency, is usually accomplished by solution of a set of linear algebraic equations. When this computation is repeated for all the candidate exciter and transducer locations, these predicted response amplitudes due to a unit amplitude oscillating force input provides strong guidance in selecting exciter and transducer locations. A second use of these frequency response functions is to select exciter size and transducer sensitivity. Third, the frequency response function is an easy, quick comparison between GVT measurements and the structural mathematical model since a measurement may be converted into frequency response function form with no operator judgment or intervention and little computation. Fourth, the predicted frequency response function may be used (usually with appropriate noise degradation) as a data set to exercise curve fitting routines, both as a data set to practice on and to screen candidate algorithms for use on the test data.

An alternative pre-test analysis that is often performed is computation of mode-shapes and natural frequencies. The predicted data is more difficult to use in this form than in the form of frequency response function. The modal amplitudes may be used as a guide in selecting exciter and transducer locations. However, no information to specify required exciter size and transducer sensitivity is available. Comparison between test measurements and the structural mathematical model requires development of natural modes and frequencies from the test data. This presents no difficulty if the test technique of sine sweeps and dwells is used because modes and frequencies is the data recorded from the test. When more sophisticated testing techniques are used, the modal parameters must be extracted from the frequency response functions by modal analysis. In a further

complication, this comparison is sometimes very difficult when it is not entirely clear how to pair experimental and analytical modes for evaluation.

2.3.7 Instrumentation Calibration

Plans should be made for all transducers to be calibrated over the frequency ranges of interest and at several representative amplitudes. Calibration sheets should be made out that can be used during actual calibration that are suitable for test report. In a computerized laboratory the calibrations will be recorded and used within the computer systems, and the paperwork minimized. For most major tests the calibration is required to be NBS traceable.

2.3.8 Photographic Documentation

Photographic documentation of the test must be planned. For engineering documentation photographs are usually needed of instrumentation layouts, shaker installations, control surface blocking and airplane configuration. In addition, still and motion pictures are often taken for use by the test customer groups.

2.4 Test Planning for Analysis Phase

2.4.1 Data Reduction Plan

A data reduction plan is necessary for both scheduling purposes and for budgeting. This plan includes an estimate of the number of frequency response functions to be analyzed, the bandwidth of interest for each major component of the

airplane, an estimate of the number of modes to be processed and anticipated problem areas. The data reduction plan is written as part of the overall test plan, and is revised as necessary after the measurements are complete.

2.4.2 Documentation Plan

A documentation plan is included in the test plan document. A written agreed on plan for documentation developed before the test is important in getting satisfactory test reports. The documentation plan should define the contents of the document and the documentation specifications.

3.0 TEST EQUIPMENT

3.1 Test Equipment for Measurement Phase

3.1.1 Test Supervision Equipment

A minicomputer is often used for test supervision. This computer, with a keyboard and paper (or cassette) tape reader, executes control programs to initiate excitation ano data acquisition, terminate excitation, terminate data acquisition and automatically perform the online data processing. This computer need not have much capacity. A standard desktop computer will suffice, or this control function may be done as a shared function in the larger minicomputer of a modal analyzer. This computer must have a standard digital data bus interface.

3.1.2 Excitation Equipment

3.1.2.1 Excitation Signal Generator

In the usual equipment arrangement incorporating electrodynamic shakers, an analogue electrical signal is input to a power amplifier. The output from the power amplifier drives the shaker. A force transducer between the shaker and the airplane is used to provide force feedback to the shaker control equipment.

Modal Analyzer

One common excitation signal source is an FFT type modal analyzer. The engineer constructs his desired force spectrum in the analyzer. The analyzer is then

operated in the inverse Fourier transform mode. The resulting time history signal output from the FFT computer is processed through a digital to analogue converter and transmitted to the shaker control equipment.

Sine Wave Oscillator

Pure sinusoidal signals are not usually used with the single point excitation/frequency response analysis method except in documenting nonlinearities. When a sinusoidal signal is required a sine wave oscillator is an excellent source. The oscillator output is patched into the shaker control panel input instead of the digital to analogue converter output.

Random Noise Generator

Bandwidth limited random noise may be created by a random noise generator in conjunction with a high pass and a low pass filter as well as by the modal analyzer. It may be advantageous to use the random noise generator for long continuous (or pure) random excitation runs (durations typically approaching one hour). This frees the modal analyzer, which may now be used during the continuous random excitation periods to perform preliminary curve fitting or other appropriate computations.

Magnetic Tape

It is often advantageous to create complex or unusual excitation signals in the laboratory prior to the test and record them on magnetic tape. The output from the tape recorder is patched directly into the shaker control panel.

3.1.2.2 Shaker Control Equipment

The shaker control panel receives the excitation signal and routes it to the power amplifiers. Output level for the power amplifiers are controlled from the shaker control panel. Some installations utilize feedback from the force transducer between the shaker and the airplane, while other systems function open loop. The shaker control panel instrumentation monitors excitation signal and output force signal.

3.1.2.3 Shaker and Shaker Attachments

The exciters usually used are electro-mechanical vibrators with several hundred pounds force capability. Vibrators used for control surfaces and tabs are smaller, in the range of 1-25 pounds force. These vibrators usually have the voice coil suspended on flextures with the voice coil attached to the airplane. Flextures are usually placed on the end of the attachment rod to reduce moment transmitted and reduce alignment difficulty. A vacuum cup has been found to be a convenient way to attach to the aircraft surface although double back tape may also be employed.

3.1.2.4 Impact Hammer

Impact hammers contain a force transducer so that the force time history of the impact may be recorded. Impact hammers are available in several sizes with various kinds of material on the impact surface. Vibration testing on airplanes with the impact hammer is not well developed and little definitive experience

exists. The work that has been done indicates that the impact hammer is potentially useful on control surfaces and other small components. The technique has proven useful on panels, wind tunnel force models and, to a limited extent, on wind tunnel flutter models.

3.1.2.5 Other Excitation Methods

Operating Inputs

Operating inputs are rarely used in ground vibration testing of airplanes. This is probably because the available operating inputs almost never excite all of the modes of interest.

In one instance where operating inputs were used, a transport airplane required a ground vibration test after a design modification. The test was conducted to measure only certain of the antisymmetric wing modes. These modes were excited by providing swept sine input to the rudder channel of the automatic flight control system. The inertia forces of the oscillating rudder provided sufficient excitation to the modes of interest.

Bonkers

On occasion an airplane fitted with bonkers for flight flutter testing has required a ground vibration test, and the bonkers have been used as an excitation source. This technique is most certainly expedient, although it appears that only the first few modes have been extracted where this approach has been used.

Unit Step Response

The unit step response has been attempted with limited success on wind tunnel flutter models. No applications of this technique to airplanes are known.

3.1.3 Aircraft Support System

3.1.3.1 Soft Support System

On many occasions the test airplane is supported on a special purpose soft support system. This system must offer low enough natural frequencies so that the support system is well separated from the elastic modes of the airplane. The system must also be stable and reliable.

3.1.3.2 Soft Tires

Frequently transport airplanes are shaken on soft tires. The landing gear oleo struts are either bottomed or overfilled with oil to eliminate any motion in the strut. Air pressure in the tires is reduced to make the tires function as soft springs. This method requires no special equipment and little preparation. It has the disadvantages that the frequency separation is not as good as a soft support system and usually the set of tires used is damaged so severely they must be discarded.

3.1.3.3 Hard Mount

Attempts have been made to rigidly constrain the test airplane at its suspension points. With care this can be successful on small airplanes. However, on large

airplanes it has proven extremely difficult to provide a stiff enough support and backup structure (which often must include the building floor and foundation).

3.1.4 Data Acquisition Equipment

3.1.4.1 Transducers

Accelerometers

Accelerometers are used for sensing response of the structure. These accelerometers are attached in a temporary manner with tape or a removable cement. Since low frequencies are usually measured at low acceleration levels, an accelerometer with good output and phase characteristics is required. The large servo-type, strain gage, accelerometer is recommended for most GVT work. Where smaller transducers are required, other more compact type transducers may be used of the crystal or strain gage type.

Force Gages

Since the accurate measurement of the force vector input to the airplane is required, a reliable force measuring transducer is used between the vibrator and the airplane. This force transducer is usually attached to the push rod from the vibrator and may be a crystal or strain gage sensing element. The gage should have a minimum of cross-talk output resulting from moment forces that are applied during the excitation.

Strain Gages

Strain gages are rarely placed on an airplane for use in ground vibration testing because the low strain levels produced during a GVT result in poor signal to noise ratios. However, strain gages placed for other purposes are used. No special preparations are necessary on the strain gage, it has ample bandwidth and phase stability, but care must be taken that the signal conditioning equipment used with the strain gages is appropriate to vibration testing rather than static load testing where most strain gages are used.

Others

Among other transducers used are displacement and velocity sensors.

3.1.4.2 Signal Conditioning Equipment

Filters

Usually the system is calibrated for amplitude and phase using a high-pass filter set at a low value of 1 or 2 Hz to eliminate zero shift arising from balance differences of each circuit.

Cathode following or charge amplifiers serve as impedance matching signal conditioning instruments for crystal transducers with high impedance. Locating the charge amplifier close to the transducers is desirable to reduce the line loss for long lead lengths.

Amplifiers

Amplifiers are required to raise the low level signals from the transducers to levels that can be tape recorded. Specifications for an amplifier include the following items:

- Linearity
- Sensitivity
- Signal to Noise
- Gain Settings
- Phase

3.1.4.3 Signal Conversion and Storage

There are two general approaches to signal conversion and storage. Although the digital system is superior and very much preferred, a discussion of the older analogue system approach is included because many organizations have the analogue systems and no opportunity to upgrade.

Digital System Approach

Anti-Alias Filters—Low pass filters are included upstream of the analogue to digital converter on each signal circuit to serve as anti-alias filters. The filters must be set to function with the sampling rate on each circuit.

Auto Ranging Amplifier—The autoranging amplifier functions in two modes. First, while autoranging it samples the incoming signal continuously to find the maximum

signal. The autoranging function is carried out on command. This is done in a GVT during typical excitation. The autoranging results in an amplifier gain factor that will produce a specified peak amplitude output. In the second mode, the amplifier function of the autoranging amplifier outputs the gain and the input signal scaled by the gain.

Analogue to Digital Converter—The analogue to digital converter creates a digital signal from its input analogue signal. The conversion takes palce either on an internal trigger (clock) or an external trigger. For a GVT all the trigger commands are usually taken from one central clock which is usually located in the modal analyzer.

Multiplexer—A digital time division multiplexer is used to amalgamate the signals from many sensors for recording serially on one device. Equipment is available which combines the functions of autoranging amplifier, analogue to digital converter and multiplexer into one unit.

Minicomputer—A minicomputer is needed to format the multiplexer output data for recording and to function as a disk or tape controller.

Disk or Tape Recorder—Disk recording is preferred over tape because it is much faster, allowing increased bandwidth (or equivalently additional channels of multiplexing). However, many disk units do not have enough capacity to record all the data for one run, and in that case one must record directly on tape and accept its limitations.

Analogue System Approach

Variable Gain Amplifiers—A separate variable gain amplifier is used for each transducer circuit. During typical excitation the test technician adjusts the gain setting on each amplifier to give a desired output signal amplitude (as monitored on an oscilloscope). The technician records the gain settings on his clipboard.

Analogue Tape Recorder—The output from the variable gain amplifiers is the input to the analogue tape recorders. Since analogue tape recorders tend to be capacity limited, several are required, running in parallel, for the usual GVT.

3.1.5 Data Verification Equipment

The onsite modal analyzer is used for data verification. In addition, monitor oscilloscopes displaying all transducers during data acquisition provide the engineer with a qualitative check on signal quality.

3.2 Test Equipment for Analysis Phase

A computer system is used for frequency response analysis. The system most commonly used is the minicomputer based modal analyzer, with an appropriate set of peripheral equipment (often including a hardware band selectable Fourier transform processor). Some organizations have chosen to perform their frequency response function analysis on the big mainframe computer. There is a trade off here - the big mainframe has more capacity and is more versatile but more modal analysis software exists for minicomputers.

4.0 TEST OPERATIONS

4.1 Calibration

The transducers should be checked over the range of frequencies of interest with several levels of known input. A calibration table should be used with a secondary standard pickup. The remainder of the electronic equipment must be checked with traceable standards to insure amplifier and tape recorders are operating within standard tolerances. Each item of equipment must have an up-to-date calibration sticker indicating the instrument is current.

4.2 Aircraft Preparation

4.2.1 Configuration

The airplane configuration tested may include modifications not typical of flight. For example, the airplane of the A-10 demonstration ground vibration test was tested with the flaps removed because they were known to be the source of a strong nonlinearity.

4.2.2 Fuel System

The ideal fuel state to shake an airplane is empty. Then there is no question of the effect of fluid interactions on the test data. Shaking the airplane empty of fuel is frequently adequate in organizations where the effect of fuel can be added to the airplane mathematical model analytically.

The next ideal fuel state is with every fuel tank either empty or completely full. In this case the fluid interaction effect is between the fluid bulk and the surrounding tank walls. Fortunately the frequencies at which this effect is significant are usually well above those important in whole airplane structural dynamics - flutter, gust, etc. Note, however, that this effect is significant at panel flutter frequencies.

The most difficult fuel state is a partially filled tank. In this case there is a fluid surface, in addition to the fluid bulk, interacting with the structure. The fluid surface in general exhibits non-linear behavior which is not only a function of vibration amplitude, but also a function of the boundaries of the fluid surface, i.e. an airplane fuel tank tested with the same volume of fuel in two different attitudes can give different dynamic characteristics.

Fuel Safety—The primary danger is not from fire but from explosion of a fuel vapor-air mixture in the ullage area of the fuel tank. This problem is more severe for airplanes fueled with JP-4 (JET-B) than with JET-A. Nitrogen inerting has usually been sufficient to eliminate the danger of explosion, although occasionally the fire safety organization will require a full purge on some systems.

4.2.3 Ejection Seat

If the airplane contains an ejection seat it must be removed unless it can be satisfactorily safetyed. Access to the cockpit must then be strictly limited to qualified personnel.

4.2.4 Oxygen Systems

The oxygen systems on the airplane must be configured to satisfy the health and safety organizations requirements.

4.2.5 Flight Control System

The flight control system of the airplane usually contains nonlinearities and often couples closely with the elastic modes of the airplane. Because of this the flight control system is modified to minimize these effects for the airplane ground vibration test. If the dynamic characteristics of the control system must be measured this is best done as a separate test. Typical modifications to the flight control system include blocking or pining the control stick (or wheel) or to block the control stick (or wheel) output quadrant so that vibratory motion of the cockpit will not induce oscillatory inputs into the flight control system. A second modification is to block (usually with shims and wedges) the control surface PCU input quadrant (powered surfaces) or the control surface actuator quadrant (manually controlled surfaces). A third measure is to test the airplane with all automatic flight control systems off or disconnected. This is so that vibration of the AFCS sensors do not cause commands for oscillatory motion at the PCU actuators.

4.2.6 Dummy Engines

There has been concern that during a GVT the vibrations induced in the jet engines on the test airplane could damage the engines. The engine manufacturers access this potential for damage for each engine design and write

recommendations. In the worst case the engines are removed from the airplane and replaced with mass-properties-equivalent dummy engines. For less severe situations the requirement may be 1) to motor the engines at all times the airplane is being shaken, 2) rotate the engine periodically during the test (typically every four hours) or, 3) no special requirement. In recent years the trend has been toward less stringent restrictions because of 1) improvements in bearing design and 2) testing with predominantly random excitation rather than sinusoidal provides a more benign environment to the engines.

4.2.7 Other Vibration Sensitive Equipment

Ground vibration testing is not an adverse environment for most equipment other than the engines because the equipment is qualified to stringent specifications. The possibility for damage to unqualified nonspecification equipment must be considered.

4.2.8 Test Equipment Installation

The test equipment installation should be rapid because the length of time the test airplane is occupied for the GVT must be minimized. This is accomplished by assembling and checking the equipment in the laboratory prior to the test, by rack mounting equipment, by making up accelerometer installation kits and by preplanning the test equipment installation for maximum effciency.

4.3 Test Operations For Measurement Phase

4.3.1 System Checks

4.3.1.1 Electronic Equipment

The usual checks of installed electronic equipment are satisfactory; exercising systems with reference and calibration signals, etc.

4.3.1.2 Aircraft Support System

The aircraft support system must first be checked for function and stability. Then the rigid body modes of the airplane must be measured; obtaining natural frequencies, damping and modeshape. This is most expediently done by setting the lower bandpass limits well below the expected rigid body natural frequencies for the initial random excitation of the airplane. Energy considerations may dictate separate runs to measure the rigid body modes, using bandwidth limited noise encompassing only the expected rigid body frequencies.

4.3.1.3 Rattles

Walk around inspections of the airplane while it is being excited at a fairly high force level is important. Any rattles present are indicative of non-linearities. This may be due to loose equipment or due to free play. Particular attention should be paid to the shims and wedges in flight control systems. Invariably some of them won't be sufficiently tight, and will need tightening or rework, possibly more than once.

4.3.2 Force Level Selection

Although excitation force level is predicted by the pretest analysis, excitation force levels to be used are selected by trial and error in the vicinity of the predicted force level. Low force levels are desired because most nonlinear systems behave in a more linear fashion at low force levels, but at low force levels the signal to noise ratios are poor. A best compromise force level is sought.

4.3.3 Data Acquisition

4.3.3.1 Excitation

The excitation signal of T seconds duration is generated in a Fourier analyzer data block in the time domain and output to the shaker through the digital-to-analog converter. The excitation signal may be of the following types:

1. Periodic random transient
2. Periodic log swept sine transient
3. Pure random

The exiciter locations and directions of excitation may typically include vertical excitation on one of the wing tips, lateral excitation on the aft body, lateral excitation on the vertical fin, vertical excitation on the horizontal stabilizer, and chordwise excitation on the horizontal stabilizer.

Force levels are determined by a combination of visual verification of actual airplane vibration amplitudes and accelerometer response signal levels as observed in the monitor scopes. The frequency range may encompass frequencies up to 50.0 Hz and may be subdivided into smaller ranges such as 0 to 10.0 Hz, 5.0 Hz to 20.0 Hz, and/or 20 Hz to 50 Hz with varying frequency resolution or time duration. Frequency resolution, f, or time duration, T = 1/ f, are sampling parameters that are functions of the structure's damping characteristics, frequency range and the sample size (or block size) of the Fourier analyzer.

4.3.3.2 Signal Conditioning and Recording

Digital Recording System

If an analogue to digital converter and a multiplexer are used, then all the analog tape recorders would be replaced by one digital magnetic tape unit as the storage device for the digitized multiplexed time histories. A multiplexer affords a significant improvement in signal-to-noise ratio over an analog system. A multiplexer with an automatic gain range amplifier affords the added benefit to improved S/N ratio by operating with an optimum gain level on each word of the incoming data stream. The force input signal measured at the shaker and the accelerometer response signals are the only required signals to be digitized and recorded on the digital magnetic tape unit. Data qualifiers such as block size, scale factor, data calibrators and frequency resolution are also stored on the digital tape with each block of data. The sampling rate of the multiplexer analog-to-digital converter is clocked by the control computer ADC. The multiplexer ADC is triggered by the data-ready pulse of the control computer so that all response time histories are periodic and synchronous with the excitation signal.

Analog Recording System

If an analog recording system is used, then on each analog wideband FM tape recorder are recorded the time domain data from:

1. The force input signal as measured from a force transducer on the shaker at the point of excitation.

2. The response signals from the accelerometers mounted at preselected coordinate points and directions on the airplane.

3. The data-ready pulse which signals the start of each sweep at T=0 of each Fourier time window. For post-test data analysis, this pulse is used to trigger the analog-to-digital converter (ADC) of the Fourier analyzer.

4. Time-code signal.

5. Voice identification.

For each test condition, there are several analog tape recorders running simultaneously depending on the number of accelerometer signals being recorded for that particular test condition.

4.3.3.3 Data for Zoom Transforms

The zoom transform is a measurement technique in which Fourier-transform based digital spectrum analysis is performed over a frequency band whose upper and lower frequencies are independently selectable. Zoom can provide an improvement

in frequency resolution and dynamic range over a baseband measurement which extends from dc to some maximum frequency, Fmax. The zoom transform operates an incoming time domain data to the analyzer's analog-to-digital converter (ADC) or on time domain data that has previously been recorded on a digital mass storage device (in real time, i.e., no samples lost). The time domain data is digitally filtered and only the filtered data stored and then Fourier transformed.

The zoom transform lends itself ideally to testing situations wherein successive ensembles of data are random in nature. If frequency resolution is improved by a factor of n over the original base-band measurement, then it follows that the time record of the input signals for a zoom measurement must be n times as long (Ref. 5).

In testing situations wherein successive ensembles of data are totally observed transients such as with periodic random transient excitation, the zoom transform is not readily adaptable. In these instances, frequency resolution is improved by increasing the number of samples or block size, N. An 8192 point transform is now available which increases the sample size capacity of the newer version of minicomputer-based Fourier analyzers.

4.3.4 Verification

The incoming data stream of both the force input signal and the monitor accelerometer response signal as seen in the display scope of the Fourier analyzer can provide a visual check of the data in the time domain. This visual verification of the signal requires some prior experience on the part of a knowledgeable test operator.

In the frequency domain, the quality of the frequency response function is checked by means of the coherence function. After the frequency response function has been calculated, the coherence function is then calculated as the next step in the Fourier keyboard program. It is defined as follows (Ref. 2):

$$\text{Coherence function} \qquad \gamma^2 = |H|^2 \frac{G_{xx}}{G_{yy}} = \frac{|G_{xy}|^2}{G_{xx}G_{yy}}$$

where

G_{xy} = cross power spectrum

G_{xx} = input auto power spectrum

G_{yy} = response auto power spectrum

If the coherence is equal to 1 at any specific frequency, the system is said to have perfect causality at that frequency. In other words, the measured output is totally caused by the measured input, or by sources coherent with the measured input. A coherence value less than 1 at a given frequency indicates some degree of noise contamination and/or non-linear distortion.

Modal analysis for selected modes and a suitable subset of all accelerometers is often performed to gain additional confidence. The goals of modal analysis to be accomplished during the test must be modest because there is limited time available to perform the analysis.

4.3.5 Nonlinearities

Nonlinearities are handled in three ways; by eliminating, by averaging or by documenting. Free play may be eliminated by shimming, blocking or preloading. Nonlinear components may be removed from the test article or may be replaced with a linear "dummy" component. The technique of averaging the measured data from random excitation produces frequency response functions that are the linear equivalent average of the nonlinear system. Nonlinearities are documented by special testing techniques appropriate to the type of nonlinearity at hand.

4.4 Analysis Phase Test Operations

4.4.1 Preparation of Frequency Response Functions

4.4.1.1 Disk File Digital Time Histories

A series of actions, none of them very automated at present, is necessary to produce digital time histories on the disk file computer storage of the modal analyzer.

If digital magnetic tape is the data storage media the problem is that the data on the tape is in time division multiplexed form. The demultiplexing operation, called unweaving, involves either selective reading of a few channels at a time from the tape using the minicomputer or exporting the tape to a big mainframe computer where the tape is rewritten into demultiplexed form, and then reading this tape into the modal analyzer.

If analogue magnetic tape is the storage media then the analogue signal is read into an analogue to digital converter and then to the modal analyzer disk, mimicing a realtime analysis of the test data.

4.4.1.2 Signal Processing

The engineer must judge the extent of modifications to the time history signals necessary to produce analyzable frequency response functions. Generally this signal processing accentuates one facet of the signal to the detriment of others. Some of the processes carried out are windowing, decimation and averaging. From these processes computation of the frequency response function via fast Fourier transforms follows directly. An alternative process which produces a frequency response function having fine frequency resolution over a limited bandwidth is called a band selectable Fourier transform (a zoom transform).

4.4.2 Curve Fitting

The Laplace modal parameters of frequency and damping, magnitude and phase can be estimated for each mode of vibration by curve-fitting a Laplace math model to the frequency response functions on the modal disc. The choice of curve-fitting algorithms is dependent upon the particular modal analysis software system being used.

4.4.2.1 Parameter Estimation Techniques

Amplitude Response

The simplest parameter estimation technique is to measure the magnitude of the frequency response at each of the frequencies where the magnitude reaches a maximum. The total response can be used as the modal coefficient. This method assumes a single degree of freedom system. Frequencies are determined visually by noting where the peaks occur in the frequency response function. No attempt is made to curve-fit a Laplace model to the data. Damping may be estimated using any of several popular techniques. Recommendation: This method does a poor job of separating modes. It is not recommended for use on complex structures.

Quadrature Response

Another parameter estimation technique is to measure the quadrature or imaginary, component of the frequency response at each frequency where the imaginary component reaches a maximum, these being the undamped natural frequencies of the system. The quadrature response is used as the modal coefficient. This method assumes a single degree of freedom system. Frequencies can be determined visually or from a power spectrum composite of the quadrature responses of all the measurements. No attempt is made to curve-fit a Laplace model to the data. Damping may be estimated using any of several popular techniques. Recommendation: This method can be used on systems that are lightly damped and that have modes that are well separated.

Circle Fit

A third parameter estimation technique is accomplished by presenting each mode of the frequency response function as a circle in the complex plane. Resonant frequency is found where the rate of change of phase angle as a function of frequency is a maximum. The amplitude and phase angle of the complex modal coefficient is defined by the location, diameter and orientation of the circle. This method assumes a single degree of freedom. No attempt is made to curve fit a Laplace model to the data. Damping may be estimated by the circle fit technique originally developed by Kennedy and Pancu. (Ref. 6). Recommendations: This method may be used on systems that are relatively lightly damped and that have modes that are only weakly coupled in the range where one mode is predominant. The actual curve fitting procedure must be an interactive process.

Least Squares

Eigenvalue solution using least squares complex exponential algorithm in time domain—Another parameter estimation technique is the least squares complex exponential algorithm which solves the impulse response form of the multiple-degree of freedom equations. The equations are non-linear in 4 unknowns and an iteration process is used to obtain a solution. The algorithm searches all measurements in the declared frequency range and constructs a composite power spectrum from the frequency response functions. The least squares error as a function of number of degrees of freedom is then printed out. From this, an estimate is made of the number of modes to input into the algorithm. Additional or "computational" modes are carried to compensate for noise or distortion in the data. A set of eigenvalues is then generated for each mode being carried in the frequency band.

Eigenvector solution using least squares in the frequency domain-With these fixed sets of eigenvalues, the partial fraction form of the equations in the frequency domain are then solved for the other two unknowns, the complex eigenvectors, for each measurement. The whole process is an automatic one, with the modal analyst having the option of accepting or rejecting the fit for any measurement.

Recommendations: This method does a good job of fitting closely-spaced modes. It has the difficulty fitting other modes in the same frequency band. It is recommended for use on multiple degree of freedom systems in conjunction with the curve-fitting technique described in the following section.

Eigenvalue and eigenvector solution using least squares algorithm in the frequency domain—Another parameter estimation technique is to obtain the eigenvalues and eigenvectors by solving the partial fraction form of the non-linear equations in the frequency domain by least squares method. The process is iterative and all four modal parameters are updated with each iteration. Starting estimates of all four parameters for each mode may be automatically generated by the system or entered by the modal analyst at the terminal. The process is interactive allowing the analyst to add or drop modes, select the number of interations, and select the type of residual function to fit the tails of modes lying just outside the frequency band.

Recommendations: This method does an accurate, dependable job of curve-fitting frequency response functions. It is recommended for use on multiple degree of freedom systems in conjunction with the curve-fitting technique described earlier in this section.

4.4.2.2 Integration of Results

The current curve fitting computer programs operate on the data from a single test run. During the entire ground vibration test runs with several different shaker locations, force levels and accelerometer layouts are usually made. Integration of the curve fitting results into a whole airplane linear mathematical model of modeshapes, frequency and damping is done intuitively. The most important aids to the engieer in doing this job are the pretest analysis and the frequency response function plots.

4.4.3 Data Display

4.4.3.1 Modal Data

The modal data can be presented graphically and in printouts of the residues along with the associated frequency and damping values of each mode of vibration. The graphics display can be in the form of animated mode shape displays of each mode as seen in the display scope of the Fourier Analyzer system. This display can be plotted showing undeformed and deformed positions for a permanent record. Mode shapes can also be graphically displayed as delta functions or vectors representing amplitude and phase at each measurement point on the airplane. These vectors can be shown in animation on the display scope and can also be plotted along with the complete outline of the airplane. Again permanent records of these vector plots can be made.

The printouts of the mode shapes are in matrix form with each row representing a measurement point on the airplane and each column representing a mode. The

residues are expressed as a magnitude vector and a phase angle in engineering units.

4.4.3.2 Frequency Response Functions

Each frequency response function can be plotted in terms of its magnitude versus frequency and also its phase versus frequency. Permanent records of these plots can be made.

4.4.4 Measures of Confidence

Five measures of confidence in curve fitting are plausibility, wild points, measured vs fit frequency response functions, modal confidence factor and generalized mass.

Plausibility is the experienced engineer's intuitive review of the modeshapes, frequencies and dampings. The data is reviewed for reasonableness in terms of prior airplane designs, development experience on the airplane under test and the experiences during the measurement phase of the test.

Wild points are readily apparent in animated modeshape plots, provided the accelerometer layout is not too sparse. The rigid body modes of the airplane are particularly good for spotting improperly installed or malfunctioning accelerometers.

Comparison of the measured frequency response function plots with the frequency response functions computed from the curve fit results is a good check on the quality of the curve fitting.

The modal confidence factor is a comparison of the curve fit modeshapes from different shaker locations. It is a measure of the repeatibility of the data. Note that a low modal confidence factor is to be expected where a shaker was located near a node point; the mode was simply very poorly excited from that point.

Generalized mass, although often referred to by investigators in the field, is not really a very good measure of confidence. In this case we are talking of a generalized mass matrix which is computed from a theoretically derived reduced mass matrix at the test measurement points, m, and from the matrix of curve fit modeshapes, ϕ. The generalized mass is computed as:

$$M = \phi^T m \phi.$$

The judgment usually made is to compare the size of the off diagonal terms with the diagonal. The ambiguity is in the lack of a metric to judge the quality of the generalized masses. If the off diagonal terms are several orders of magnitude below the diagonal then obviously the modes are mass orthogonal. If the off diagonal terms are of the same order of magnitude the modes are definitely not mass orthogonal, and the process is in error somewhere. However frequently the generalized mass falls between these two cases and no clear guidance is given.

4.4.5 Modal Analysis Software Systems

The state of the art in modal analysis software systems is developing rapidly. The manufacturers of modal analysis hardware systems offer modal analysis software packages with their equipment. Since the equipment is based on general

purpose minicomputers, the user and the researcher may augment this ensemble with more advanced software of his own. One such package is that developed at the University of Cincinnati and the University of Luven. A copy of this package is delivered to the Air Force under this contact.

4.5 Follow-On Activities

Feedback into the airplane design loop is the end product of a ground vibration test. The most frequent feedback mechanism is verification and modification of the mathematical model of the airplane. Less frequently (in the United States) the mechanism is the creation of a mathematical model of the airplane directly from test data.

5.0 GENERAL GUIDELINES

5.1 Common Problems

5.1.1 Friction

The friction between structural components/fixtures is present for most GVT tests. For riveted structures, this situation is accepted and is similar in structures of similar design.

Friction in nacelle engine mounted systems has been of considerable interest with engines mounted on wing pylons and must be tested with variable force amplitude.

Control surfaces often have variable friction and break-away forces that must be dealt with carefully. Power actuated controls must be tested with power-on to determine working frequencies and transfer functions.

5.1.2 Free-play

Free-play in control surfaces must be carefully treated. First, measurements must be made with and without power to determine static free-play and bring within tolerance. Then vibration tests must be conducted with frequency-amplitude studies to determine the effect of free-play on the dynamics of the surface.

5.1.3 Damping

Structural damping values are usually determined for each resonant condition of the airplane in the GVT. These measurements may be made at several amplitudes of excitation to determine the amount of non-linear effects on damping values.

5.1.4 Airplane Asymmetries

Considerations must be made to configurations where asymmetric loading takes place. This could be from internal equipment placement or for combinations of external stores.

5.1.5 Closely Spaced Modes

Closely spaced modes are those which are sufficiently close in frequency and overlapping in off resonant response that separation of these modes into frequency, damping and modeshape is not readily accomplished. Two measures may be taken when the online frequency response functions or the pretest analysis indicate closely spaced modes are a problem: 1) take an additional data set with a long pure random record so that fine frequency resolution may be achieved in the neighborhood of the closely spaced modes via zoom transforms. A reference accelerometer frequency response function may be checked in real time using a hardware zoom unit, which will assure that sufficient frequency resolution has been acquired so that the closely spaced modes may be resolved during curve fitting. 2) a second measure that aids in separating modes is to repeat the single point excitation at several locations. This aids because modes which appear to be closely spaced on frequency response functions from one excitation

often will be much less coupled on frequency response functions from another exciter location.

Given a comprehensive set of measurements (i.e. frequency response functions for all accelerometer locations and shaker locations with adequate frequency resolution and signal to noise ratio) most closely spaced modes may be separated during the analysis phase of the test. This analysis will involve using data from several different accelerometers and different exciter locations, possibly in linear combinations, and attempting curve fitting by several multiple degree of freedom approaches, perhaps with many different signal conditioning processes. Zoom transforms will be used as necessary to achieve frequency resolution. Although this iterative process may be just as time consuming as modal tuning, it is substantially less costly because it is performed off-line by one person on a computer whereas the modal tuning is done during the test time, occupying the test airplane, all the test equipment and the full test crew.

5.1.6 Strut Mounted Wing Engines and External Stores

Nearly identical repeated subassemblies on the wing give rise to closely spaced modes, for which approaches are suggested in sections 5.1.5. A second problem arises with nonlinearities in engine and external stores. Usually the nonlinearities are mild enough that they may be averaged out, and documented in separate testing as necessary. A third problem is in repeatibility of bomb installations. Special care must be taken to insure that the bombs are hung the same every time, and that free play and friction are absolutely minimized.

5.1.7 Hydraulic Pressure Source

A hydraulic mule is usually used to provide hydraulic pressure to the airplane during a ground vibration test. The mule interferes with the test in two ways: 1) pressure pulses are transmitted from the pump in the mule into the airplane through the hydraulic tubing, and 2) acoustic noise from the mule exciting the airplane. Two approaches to this problem are suggested. The first approach eliminates the problems due to the hydraulic mule. This approach is applicable if the airplane hydraulic system requires only low flow rates while data is being taken. This approach is to charge a large accumulator, perhaps 50 gal., before the data run, then isolate the mule out of the system with an appropriate set of valves, turn the mule off and utilize the accumulator as the pressure source during the data run.

A second approach must be used if flow volume beyond the accumulator capacity are required. The mule will have to be used as the pressure source. The pressure pulses are attenuated by placing an accumulator in the output line from the mule, as close to the mule as possible. The accumulator should be tuned to remove the major component of the pressure pulse. The acoustic transmission is minimized by placing the mule outside the hangar. If this is not possible, completely surround the mule with acoustic isolation material.

5.1.8 Local Mode Response

The accelerometers located near the shaker in a single point excitation will sense the local modes as well as the global modes of the airplane. If the primary objective of the test is measurement of global modes, as opposed to local, the

best signals for this purpose will come from the accelerometers on the symmetric other side of the airplane from the shaker. Their signals will contain very little local mode motion. For global modes heavily instrument the opposite side of the airplane from the shaker. For local modes heavily instrument on the same side of the airplane as the shaker.

5.1.9 Landing Gear

Occasionally it is necessary to shake the landing gear. These tests are run with the gear down and locked and the airplane jacked so that the wheels do not touch the ground. The dynamic characteristics of the gear, as installed on the airplane, are desired. This test is difficult because the landing gear contains a number of nonlinearities, some of which are not very reproducible.

The large number of joints in the landing gear are the source of free play and friction. When the gear is cycled the free play and friction do not reproduce. The free play must be preloaded out as much as possible. The friction effects may be mapped by testng at several different force levels. This should include the lowest possible force level, which will minimize the effects of free play and friction. To control the effect of the oleo strut it should be either preloaded with a suitably high strut extend pressure or overfilled with oil.

5.2 NOTES

5.2.1 Safety - People

Since some of the accelerometer locations are well above the floor, crew stands must be used for access. These stands must meet standard aircraft safety codes with railings around all platforms and mechanical locks for hydraulic jacks. Personnel must use harnesses whenever they are working on the wing, fuselage or tail surfaces that are securely tethered to prevent falling.

5.2.2 Safety - Airplane

All testing is accomplished with a defueled and purged fuel system. The aircraft must be securely mounted, if normal landing gear is not used for support, with adequate safety precautions. Stands that are to be used for vibrators must be sturdily built and secured adequately to preclude damage to aircraft. Powered control surfaces must be locked adequately before attachment of vibrators to prevent inadvertent control motion.

5.2.3 Force Level Selection: A-10 Test Experience

Several excitation force levels were used during the demonstration A-10 ground vibration test. The best signals in the A-10 test were achieved at 5 pounds RMS (3-40 Hz bandwidth) on most main surfaces and at levels as low as .2 pounds RMS on control surfaces. At these levels there is very little visible motion on the airplane, and the test crew must be very watchful that a test observer does not touch the airplane and inadvertently degrade the data set being taken. Part of

the rationale that the lowest force level that gives good signals is desirable for determining linear mathematical model characteristics is:

1. The blocking and shimming used to restrain control surface and other free play is more effective at lower vibration levels.
2. Free play in many control surfaces, landing gear uplocks and other components remains preloaded out via gravity resting the component against a stop, provided the vibration level is low enough.
3. Non-linear springs usually exhibit more nearly linear characteristics at low vibration amplitudes.
4. Hydraulic actuator feedback mechanisms often have a dead band; therefore the chance of undesired feedback is minimized at low vibration amplitudes.

5.3 Equipment Portability And Van Installation

For portability the test equipment should:

1. Be modular with components small enough to be handled by one man
2. All equipment interfaces must be via standard specification interconnects (e.g., IEEE 488-1975 specification for digital data bus)
3. Pieces of equipment that perform identical functions must be interchangeable
4. Reliable high quality connectors must be used

For a van installation the following additional requirements are suggested:

1. All equipment be rack mountable
2. All racks installed in the van be shock mounted

3. Equipment racks be located in the van to give adequate rear access

4. Adequate space provisions be made in the van for cable runs

5. Air conditioning in the van be sufficient to remove the maximum design electric power coming into the van plus $100^{O}F$ exterior temperature. Heating should be sufficient for $0^{O}F$ exterior temperature and no electronic equipment operating.

6. All equipment should be adequately durable to withstand both the operating and the van transport environments, especially with regard to

   -vibration

   -dust

   -temperature

   -humidity

   Note that many items of equipment which are suitable for use in a laboratory or computer room are not suitable for field use in a van.

7. A voltage isolator should be installed in the van input electrical power line.

6.0 GVT SOFTWARE

This section contains a users manual and software listing for the ground vibration test computer programs furnished to the Air Force by the University of Cincinnati under this contract. This software is operational on the Hewlett-Packard 5451B.

6.1 Users Manual

UCME/KUL

MODAL ANALYSIS

SYSTEM

5451C WITH HPIB

VERSION
4/21/80

Table of Contents

INTRODUCTION	CHAPTER 1

This Modal Analysis System software is a HP 5451C contributed program which allows one to perform a complete modal analysis of a mechanical structure with the use of the 5451C hardware and the University of Cincinnatti / University of Lueven software. This system takes advantage of the 5451C hardware (with a few exceptions) to make the necessary measurements to define a structure's modal parameters; in addition, special software has been included in the form of 5451C User Programs which enable one to extract the modal parameters from measured data, output these results in printed form, and obtain animated displays of the structure's modes of vibration.

This document gives a detailed decsription of the Modal System and its operation. For best results, it is recommended that the user read and understand this entire document before attempting to operate the system. If this is done, one will be able in a short time to take advantage of the full range of system capabilities and to overcome any operational difficulties which may arise. In chapter 8 there is a "canned" step by step example of processing a given set of measured transfer functions to extract the modal parameters.

SYSTEM OVERVIEW	CHAPTER 2

2.1 HARDWARE REQUIREMENTS

5451C Base System which includes:
- 2648 terminal
- 7900 disc
- 64K memory

2.2 HARDWARE OPTIONS

- 2631A Line Printer (HPIB)
- 2631G Line Printer (HPIB)
- 2748B Photoreader
- 2895B Paper Tape Punch
- 7210 Digital Plotter
- 9872B Digital Plotter
- 7245B Digital Plotter
- 7970 Magnetic Tape
- Option 600 5440A Mainframe
- Option 620 54420A Digital to Analog converter
- Option 640 54440A Low Pass Filter
- Option 670 54470A PreProcessor

2.3 USER PROGRAMS

User Program 0088 --- Data Annotation

User Program 0090 --- Test ID & Setup

User Program 0009 --- Modal Program

User Program 0040 --- Hardware Zoom Setup (option 670)

User Program 0045 --- Zoom Measurement Program

User Program 0100 --- Filters (option 640)

3

2.4 DATA SPACE REQUIREMENTS

There are two coreloads located on the modal disc. The first coreload contains the modal software (Y90,Y9) for extracting the modal parameters from the test data. The second coreload contains a modified 5451C operating system.

The first coreload (coreload 0) is used in conjunction with overlays stored in file 8 on the disc. The amount of data space available in the Modal System is determined when the Fourier system together with the largest overlay (overlay 10) is first excuted. The maximum block size that can be stored to the disc is 1024.

During the operation of the system, some or all of the total data space available will be allocated by the Modal System (in the K 0 command of the Data Setup section which is usually performed first) for storing system parameters, modal coefficients, and data for the animated mode shape displays. The Modal System allocates space for these items in terms of time domain, (block size 1024) data blocks required to perform the most important Modal functions. Storage may take from one to four BS 1024 data blocks, depending on the number of structure test points entered when the K 0 Data Setup function is performed. The number of blocks required to store modal coefficients may be computed as follows:

$$\text{Number of Blocks} = \frac{3 \times \text{No. of Modes} \times \text{No. of Points}}{1024}$$

4

Therefore, if storage for 10 modes and 150 points was desired, the system would require

$$\frac{3 \times 10 \times 150}{1024} = 5$$

data blocks for storing modal coefficients.

Based upon the maximum number of test points, the data space for modal coefficients will be allocated and the maximum number of "modes per session" calculated. If mode shape information for more modes is required, the process of parameter estimation of the test data will need to be repeated.

The system always considers block 0 and 1 to be "available" since the data arrays they contain can be recreated if the other system blocks are intact. These "available" blocks may be used in normal 5451 operations without affecting the parameters stored by the Modal System in upper data space.

2.5 DISC SPACE CONSIDERATIONS

The Modal System uses a data arrangement for the HP 7900 Disc which allows disc data records 0 through 819. Of these records 0 through 750 are typically used for data (transfer functions), and 751 through 799 are used for storing modal parameters and setup information from User Program Y 9. Test setup information from Y 90 is stored in disc file 7 records 1 through 19, file 7 records 20 to 39 can be used to store variable parameters for use by the 5451C measurement coreload (coreload 1).

2.6 FOURIER KEYBOARD FUNCTIONS

With minor exceptions, all Fourier System keyboard functions contained in the Modal System coreload (coreload 0), perform in exactly in the same manner as the standard 5451 enviroment (see the 5451C Operating Manual). The basic differences are that there are no "Gold Key" functions, i.e. no variable parameters and the graphics commands must be implemented using the Y 5800 series user programs.

The second coreload contains a standard 5451C operating system with some modifications so that it is compatiable with the modal software. The differences include: 1.) there is no overlay swaping capability 2.) the data headers have been rearranged 3.) the maximum block size that can be stored to the disc is 1024. The 5451C coreload has built in, User Programs 5,6,88,100, the digital to analog converter (DAC) and the hardware Zoom (option 670).

2.7 MODE SHAPE PROGRAMS

User Program 0009 is the software which contains the operational logic of the Modal System. This program is entered from the Fourier System in the same way as a standard User Program -- that is, by entering " Y 9 " on the keyboard or terminal. Once the program has been entered, there are a variety of mnemonic commands available which direct the system to perform various functions. Most of the rest of this manual discusses this structure and the uses of each of the commands.

Within Y 9 there are three monitors, and each monitor has associated with it a set of available commands. The monitors in the Modal System are as follows:

DATA SETUP AND DISPLAY MONITOR -- " * " MONITOR

CONNECTIVITY MONITOR ------------ " C " MONITOR

CIRCLE FIT MONITOR -------------- " D " MONITOR

The characters (if any) associated with each monitor are the characters printed on the terminal after a user-entered command has been executed. They signify that the system is now waiting for a new user command to be entered.

Once the program has been entered, you interact with the system through the system terminal or Fourier Keyboard. You communicate to the system by entering commands, parameters, and data in turn. The system communicates with you by printing out messages, warnings, parameters, and data as requested or needed.

Functionally, the Modal System can be broken into four sections, each of which is described in detail in a seperate section of this manual.

2.7.1 Data Setup Section

Using the appropriate commands, the details of the test setup, a spatial description of the structure being tested, and the order in which the structure's points are to be displayed (display sequence) are entered into the system.

2.7.2 Parameter Estimation Section

This section allows the user to identify the modal parameters (frequency, damping and complex coefficient) of up

to 10 modes from the frequency response data, print the list of parameters for inspection, and save the results of this process to the disc. This process may be performed on measurements taken in any of three directions at as many as 250 structure points.

2.7.3 Data Display Section

Using the data accumulated in the Data Setup and Acquisition Sections, you may construct an animated display of the test structure's modes of vibration. In addition, the animated modes of individual structural "components" (see section 3) may be displayed separately for closer examination. You also have a wide variety of commands available which control such items as the size and position of the display and the amplitude and speed of the animation.

2.7.4 Data Presentation Section

Once a display has been calculated and displayed on the 5460 display unit, a plot can be initiated to the 2648A terminal, 7210 plotter, 9872 plotter, 7245 plotter, or a raster dump from the 2648 terminal to a 2631G line printer. Display of ASCII text to the 5460 display unit is also available for use in movie or video tape. After the necessary frequency response measurements have been made on the test structure, the above four sections of the Modal System enable you to perform a complete modal analysis of that structure.

The above four sections of the Modal System are set up to run in a dynamic overlaying environment. In other words, if an operation is requested that is available in only one of the programs, that program (in overlay form) will be loaded and executed. To accommodate this feature, the 13 required overlays (out of a total of 14) must be loaded into the disc in order, and the largest overlay (10) must be executed first allowing the data space to reallocate. Thereafter, any other

overlay could be loaded but data space must not be reallocated.

2.8 SYSTEM INITIALIZATION

When the Modal System is entered for the first time, it will automatically perform some initialization (further initialization is performed during a K 0 command). Once the initialization has been performed, it is never performed again (in normal operation) unless the original software is reloaded into memory, the initialization is then performed when the first " Y 9 " call is made after each such reloading.

2.9 SYSTEM BLOCKSIZES

When the Modal System is entered by the call " Y 9 " the system records the current blocksize (denoted "external blocksize) and then operates from an "internal blocksize" which is dependent upon the section of the program being used. These blocksizes are determined as follows:

DATA SETUP SECTION ---------- "INTERNAL" BS = 1024

DATA AQUISITION SECTION ----- "INTERNAL" BS = "EXTERNAL" BS

DATA DISPLAY SECTION -------- "INTERNAL" BS = 1024

The "internal" blocksize of the Modal System may not be changed.

When the program is exited normally (that is, by using

commands) the external blocksize is always restored. If the program is aborted by pressing "RESTART" on the keyboard, the blocksize resulting will be the "internal" blocksize.

In general, before entering the Modal System, it is advisable to set the blocksize (using the Fourier "BLOCKSIZE" command) to the value desired for the test. With this version, the measurements will be made using the 5451C software in coreload 1, rather than the Modal System software in coreload 0. Consequently the block size normally used in the Modal System software will be 1024.

DATA SETUP	CHAPTER 3

3.1 Overview

There are two phases of the Modal System setup. A test setup using User Program Y 90 and a data setup using Y 9.

3.2 User Program Y 90

This program is a utility program written to handle operations connected with the modal package that due to space or convenience could not be programmed elsewhere.

Three primary functions are handled within Y 90. The first function is that of inputting test set-up information that will be stored in the header with each data record stored to the disc by User Program Y 88. The second function provides three forms of run logs for a disc with data stored in the format generated by Y 88. The third function is that of correcting information stored in the header area of each disc data record.

The program operates in a monitor mode as does the mode shape program. The prompt character generated by Y 90 is "@ ". This character is written on the terminal and indicates that the program is ready for the next command. Commands can be entered from the Fourier keyboard or from the terminal.

To enter the program, overlay 0 must be in memory. At bootup, overlay 0 is automatically brought into memory. If

some other overlay is currently in memory a "Mass Store" 38 0 ENTER, followed by a Mass store 18 1 Enter, will bring in the correct overlay. With the correct overlay in memory a Y 90 command is entered from the Fourier keyboard or the terminal. After the prompt character is printed, any of the commands which follow can be entered.

3.2.1 CLEAR - CL

CL N1 N2 *** CLEAR BUTTON***

N1 = First record of disc file 1 data space to be cleared (default value = 1)

N2 = Last record of disc file 1 data space to be cleared.

(If N1 is given, then N2 default value = N1)

(If N1 is not given, then N2 default = 819)

When data is stored to the disc a header with test information is also stored. This command resets one word of the header so that the Y 88 program will know that the data record is available for storing new data.

This command does not alter the data or the test setup stored with the data. In case a record is accidentally cleared, it can be "uncleared" with the /R (REPLACE) command described later.

3.2.2 KEYBOARD - K

K N1 N2 *** KEYBOARD BUTTON ***

This command is used to input the test setup information

N1 = 0 (default value)
Enter test I.D. and date

N1 = 1
Enter model number, serial number and calibration of load cell and transducer(s)

N1 = 2
Enter zoom information if zoom processing is used, and test type (random or impact)

N2 ≠ 0 (default value)
Allows input of information required by part N1 of this test setup.

N2 = 0
Initializes all information associated with that part of the test setup that is specified by N1. Only parts 2 and 3 can be initialized by specifying N2 = 0.

The calibration numbers for the transducers are stored as real numbers. If the calibration numbers is positive it represents a constant by which all data in the block can be scaled. If the calibration is negative it represents the disc data record where the appropriate calibration curve is stored. If the calibration is zero then no calibration is specified. User Y 90 does not perform the calibration of the data.

The test I.D. is comprised of 10 ASCII characters. The I.D. should be left justified, i.e., do not enter spaces before the first letter of the I.D.

3.2.3 LIST /L

/L N1 N2 N3   *** LIST BUTTON ***

N1 = 1

Run log type 1, listing is in order of disc data records between N2 and N3 that contain the test I.D. and zoom range specified. After the /L 1 command is entered, the user is prompted for the test I.D. and zoom range. If "ZA" is specified for the zoom range, then all zoom ranges are listed. The Analog In (RA) button is equivalent to entering ZA at the terminal.

N1 = 2

Run log type 2, listing is in order of point numbers. Shows data records between N2 and N3 that contain data stored with test I.D. and zoom range entered by the user. A specific zoom range between Z0 and Z5 must be entered. A negative disc record number indicates a negative transducer orientation.

N1 = 3 (default value)

Run log of all test I.D.'s and zoom ranges stored on the disc between records N2 and N3.

N1 =4

Searches disc between records N2 and N3 for records stored with the specified test I.D. Each record is checked for zoom range. The minimum frequency and delta frequency for each zoom range is stored. After all zoom ranges in records checked, are found, they are printed out with minimum, center, maximum and delta frequency for each range. If multiple frequency information is found for any zoom range a warning is printed for each record with the different frequency information. Switch register bit 15 can be used to supress the warning.

N2 = first record of search (default value = 1)

N3 = last record of search

(If N2 is given, N3 default = N2)

if N2 is not given, N3 default = 819)

The output device is selected by the switch register (bit 6 = line printer (HPIB device), default = terminal). If the output is a line printer, then the number of lines per page is adjusted for an 11 inch page. If the output device is the terminal then a RESET PAGE command is sent to the terminal before the first page is listed. The number of lines per page is adjusted to just fill the terminal screen. If switch register bit 0 is on then the paging feature is defeated and the output consists of continuous lines with a single header at the beginning of the list. Paging resumes when bit 0 is turned off.

3.2.4 STORE - X>

X> N1 *** STORE BUTTON ***

N1 = Disc data record where test setup information will be stored (default value = 19)

When setup information is entered using the K (KEYBOARD) command the information is in computer memory only. The STORE command stores this information in record N1 of the disc data space.

3.2.5 LOAD X<

X< *** LOAD BUTTON ***

N1 = Disc data where test setup information has been stored (default value = 19).

This command recovers the test setup information from disc data record N1 and places it in computer memory. Before returning to the monitor mode the test I.D. and the date are printed on the output device.

3.2.6 PRINT - W

W N1 N2 N3 *** PRINT BUTTON ***

N1 = 0

Prints test I.D. and date to the output device specified by the computer switch register (bit 1) or default = terminal, bit 6 = line printer).

N1 = 1

Print out information entered through the KEYBOARD 1 (K 1) command.

N1 = 2

Prints out information entered through the KEYBOARD 2 (K 2) command.

N1 = (defaulted)

Prints put all test setup information entered through The KEYBOARD command. Any section initialized and containing no setup information will not be printed.

N1 = 4 N2 N3

This command prints out all test setup information stored in the header area of record N2 if N3 is not entered. If N3 is entered then just the information in header word number N3 of record N2 is printed out.

As mentioned above, the switch register determines the output device. If bit 4 is turned on, then the setup is dumped to the paper tape punch. No output is made to any other device. After punching out the tape, the prompt character will be printed on the system terminal.

3.2.7 SUBROUTINE - <

< *** SUBROUTINE BUTTON ***

This command causes control to be returned to the Fourier system.

3.2.8 POINT - /.

/. *** POINT BUTTON ***

N1 = Point number to be searched for.

N2 = First disc data record to be checked
(N2 default value = 1)

N3 = Last disc data record to be checked
(If N2 is given, N3 default value = N2)
(If N2 is not given, N3 default value = 819)

This command searches data records N2 to N3 for data with response point number N1. When a record is found that has point N1, then the point number, response transducer orientation and the disc data record are printed out.

3.2.9 INTEGRATE - $

$ N1 N2 *** INTEGRATE BUTTON ***

N1 = first disc data record to be checked
(N1 default value = 1)

N2 = last disc record to be checked
(If N1 is given, N2 default value = N1)
(If N1 is not given, N2 default value = 819)

The program formerly used to store data to the disc used channels in the data space near the end of the data block to store the test I.D., date, point number and transducer orientation. This format is not compatible with the new mode shape program. The INTEGRATE command allows the user to change the format by searching from record N1 to N2 for the data stored with the old test I.D. (The user will be prompted for this information). These records are restored on the disc with the new format using the new test I.D. entered through the KEYBOARD 1 (K 1) command, and pertinent information entered through K 2 and K 3 commands. The date, point number and transducer orientation are read from the old format and added to the new format. Information concerning minimum and delta frequencies will not be stored with the data. These may be added using the REPLACE command. Test type, load cell information and exciter position and direction will be stored, if entered. When a record is changed, the point number and orientation are outputted to the terminal unless bit 15 of the switch register is on, in which case, the program continues but no output is printed.

3.2.10 PHOTOREADER - R

R *** PHOTOREADER BUTTON ***

This command is used to read a punched paper tape of a test setup. The tape must have been punched out using the PUNCH (P) command or the WRITE command with bit 4 turned on. When this command is given, a pause is executed which halts the computer giving the user time to load the paper tape reader. When the reader is ready the user simply pushes the RUN button on the computer.

The same action will result if a KEYBOARD (K) command is given with bit 5 of the switch register turned on.

3.2.11 PUNCH - P

P *** PUNCH BUTTON ***

This command punches out a paper tape of the test setup. The same action results if a WRITE (W) command is given with bit 4 of the switch register turned on.

3.2.12 REPLACE - /R

/R N1 N2 *** REPLACE BUTTON ***

N1 = first disc data record where test setup information is to be corrected. (N1 default value = 1)

N2 = last disc record to be corrected.
(If N1 is given, N2 default value = N1)
(If N1 is not given, N2 default value = 819)

This command is used to correct header information. All records between N1 and N2 will be changed regardless of test I.D. or zoom range. The information that can be corrected by using this command is that which is independent of the transducer. This would be, for example, test I.D., zoom range, load cell information or frequency information. After giving this command, the user may request a list of header word numbers where changes may be made.

If this command is being used to "unclear" disc data records accidently cleared using the CLEAR (CL) command, the user should specify header word number 6. No further input is required in this case.

3.2.13 CONVOLUTION - CV

CV N1 N2 *** CONVOLUTION BUTTON ***

N1 = first disc data record of search
(N1 default value = 1)

N2 = last disc data record of search
(If N1 is given, N2 default value = N1)
(If N1 is not given,N2 default value = 819)

This command is used to correct header information associated with the response transducer. Disc data records N1 to N2 are searched for either a transducer number (1,2 or 3) or a transducer serial number. The only valid transducer numbers are 1,2, or 3. If an invalid transducer number is entered, then it is assumed that the search will be on a transducer serial number which the user is then asked for. Each time the correct transducer number or a transducer serial number id found, the corrected information is placed in the specified header word.

3.2.14 INTERCHANGE - X

X N1 N2 *** INTERCHANGE BUTTON ***

N1 = first disc data record of search
(N1 default value = 1)

N2 = last disc data record of search
(If N1 is given, N2 default value = N1)
(If N1 is not given, N2 default value = 819)

This command is used to interchange transducer information. Disc data records N1 to N2 are searched for point number and transducer number. The user must enter a list of where and how the transducer information is to be reorganized. For example, if the number of response directions is three then three lines should be entered when asked for new and old

transducer numbers. If the following were entered:

1, 3
2, 1
3, 2

Then the information that was stored where transducer number 3 was, will be stored where transducer number 1 was. Since the transducer number can also be interchanged, the above numbers refer to the transducer numbers before the interchange is performed.

The user must also enter a list of header word numbers corresponding to the information that is to be interchanged. Word numbers 19, 47, 48, 51 and 79 can be interchanged, however, word 51 (transducer number) specifies which data block that data came from when user program Y 88 stored it, and should probably not be changed.

Finally, the user must enter a list of point numbers that are stored between disc data records N1 and N2. The method of entering these point numbers is the same as for entering the connectivity file in the mode shape program. Two numbers may be entered per line (N3, N4). If N3 is not equal to N4 then points N3 through N4 are added to the list begining with N3 and ending with N4. If N4 is not entered, then only N3 is added to the list. If N3 is less than or equal to zero then the list is terminated. No editing of the list is allowed. The user may then request a list of the point numbers. The point numbers should be in the same order as they are stored on the disc. This minimizes the amount of search time required to find the needed data records.

The program starts with disc data record N1 and begins searching for the first point number in the list. Each time the correct point number is found, the data is checked to be sure that the transducer number has not already been found. If at any point in the search, an error is found involving a particular point number, an error message is printed out giving some information as to the type of error and the point number is skipped, i.e. the headers are not altered. These points can be looked at later to determine why the error occured.

Errors that can occur are:

1) A point at either end of the search range may not be entirely within the range which means that fewer directions than the number of directions specified will be found.

2) The point may have been repeated within the search range resulting perhaps in the same transducer number being found twice.

3) The transducer number may not be a valid number (1, 2 or 3).

If a point is repeated within the search range, either enter that point in the point number list each time it is repeated or omit it and go back later using a search range that covers only one of the sets of data at a time. Otherwise, only the first occurance of that point number will be interchanged. When the search reaches later occurances of the point number, it will be searching for other point numbers and nothing will be done to these.

3.2.15 SWITCH REGISTER OPTIONS

OUTPUT CONTROL

Bit 0 - continuous run log output, no paging

Bits 3-8 are checked, lowest numbered bit that is on sets logical unit number of output device. Default (no bits on) sets logical unit number to 1 (terminal).

Bit 4 - punch

Bit 6 - line printer

INPUT CONTROL

All information is inputted through the Fourier System keyboard or the terminal except for when reading a punched paper tape of a test setup.

Bit 5 - photoreader input.

PROGRAM CONTROL

Bit 14 - exits from certain portions of the program:
(/R, X , CL, /L, W , CV, /.)

Bit 15 - supresses print out during run logs and integrate command. Print out resumes when bit 15 is turned off.

Before entering the monitor mode bits 4, 5, 14, and 15 are turned off if found to be on. Bit 0 is turned off after any run logs.

3.2.16 HEADER WORD NUMBER INFORMATION

The following may be corrected using the REPLACE (/R) command.

WORD #	USAGE
ASCII STORAGE AREA	
10	TEST ID
24	EXCITER ORIENTATION
26	DATE
30	TIME
34	DATA TYPE CODE
36	ZOOM RANGE
INTERGER STORAGE AREA	
45	RESPONSE POINT NUMBER
46	EXCITATION POINT NUMBER
49	LOAD CELL MODEL #
50	LOAD CELL SERIAL #
REAL STORAGE AREA	
75	MINIMUM FREQUENCY
77	DELTA FREQUENCY

The following may be corrected using the CONVOLUTION (CV) or INTERCHANGE (X) command.

WORD #	USAGE
ASCII STORAGE AREA	
19	TRANSDUCER ORIENTATION
INTEGER STORAGE AREA	
47	RESPONSE TRANSDUCER MODEL #
48	RESPONSE TRANSDUCER SERIAL #
51	RESPONSE TRANSDUCER NUMBER
REAL STORAGE AREA	
79	DATA CALIBRATION OR RECORD #

3.3 USER PROGRAM Y 9

The Data Setup Section of the Modal System is entered by typing " Y 9 " on the system terminal. The program will then respond by printing a " * " on the terminal, signifying that you are currently operating from the " * " monitor.

3.3.1 STRUCTURE DESCRIPTION

Knowing how to describe the test structure to the system in the Display Setup Section is of the utmost importance in obtaining meaningful displays of the analysis results.

The Modal System allows you to describe a test structure in terms of up to 10 component coordinate systems, each component system having its own origin and orthogonal orientation with respect to one global coordinate system. Once these component systems have been defined, all structure measurement points may be described relative to these systems. Furthermore, points may be described within the component

coordinate systems in either rectangular or cylindrical coordinates, following certain guidelines discussed later.

To enter the data setup mode, a command is entered from the Fourier System or the terminal. The Modal System is entered and a program will respond with an " * " prompt being typed on the terminal. This indicates that it is in the monitor. The Data Setup mode is then called by the following commands:

3.3.2 KEYBOARD - K Commands

K N1 *** KEYBOARD ***

The basic procedure is as follows. Using the "KEYBOARD" button, the sequence required for setup is:

K 0 Test Setup Information

K 1 Structure Components

K 2 Structure Coordinates

K 3 Structure Connectivity

K 4 Modal Coefficients

After each of the commands, questions or input will be required as explaned in the following sections.

N1 = 0

The test ID, date and number of test points are requested. The maximum number of modes to be analyzed per session will be calculated. A request to clear data from a previous setup (components, geometry, connectivity, and modal coefficients) or only the current modal coefficients is made.

Test ID	=	ten characters
Max. test points	=	250
Max. modes	=	10
Max. # of components	=	10

N1 = 1

The X/Y/Z coordinates of each component origin with respect to the global system must be inputted (X,Y,Z). The orientation of the component coordinate system axis with respect to the global system axis (IX,IY,IZ) and the code for rectangular or cylindrical coordinate system (IC) is also inputted.

The code for inputting the orientation of the component coordinate system axis is used to determine the direction of the x, y, z axis in the component system with respect to the global system axis. A plus or minus one, two, or three is inputted for the x, y, z, axis respectively. For example, if the y axis of the component runs in the +x direction of the global system, then a +1 is entered for IY. If the z axis of the component runs in the negative y- direction of the global system, the IZ = -2 etc. The use of direction cosines in not allowed.

The code for the type of coordinate system is one (1) for rectangular and zero (0) for cylindrical.

N1 = 2

The point number, x, y, z, coordinate of the point, and the component number is inputted for each point. A zero or negative entry of the point number will terminate the entry. To change a point or to edit, simply reenter the data for the desired point.

N1 = 3

This is the input for the connectivity of the

structure. Due to the complexity of this input, the next section describes this input.

N1 = 4

This is the modal coefficient input and output command. The mode number, point number, and x, y, z, deformation and phase angle values can be inputted.

The data inputted during the keyboard entry can be printed out with the print command from the display monitor.

As an example of how the points on a structure may be spatially described to the system, let us consider the structure of figure III-1 and assume that we wish to describe this structure in terms of two components systems, one for the "box" and one for the "cylinder". Let us also assume that we wish to describe to the system the spatial locations of the points marked "PT 1" and "PT 2" in terms of the two component coordinate systems.

We must first tell the system the component origins in rectangular coordinates (X,Y,Z) With respect to the global origin and the global axes. The origin of component system 1 is thus determined to be (3,0,2), while that for system 2 is (4,1,1).

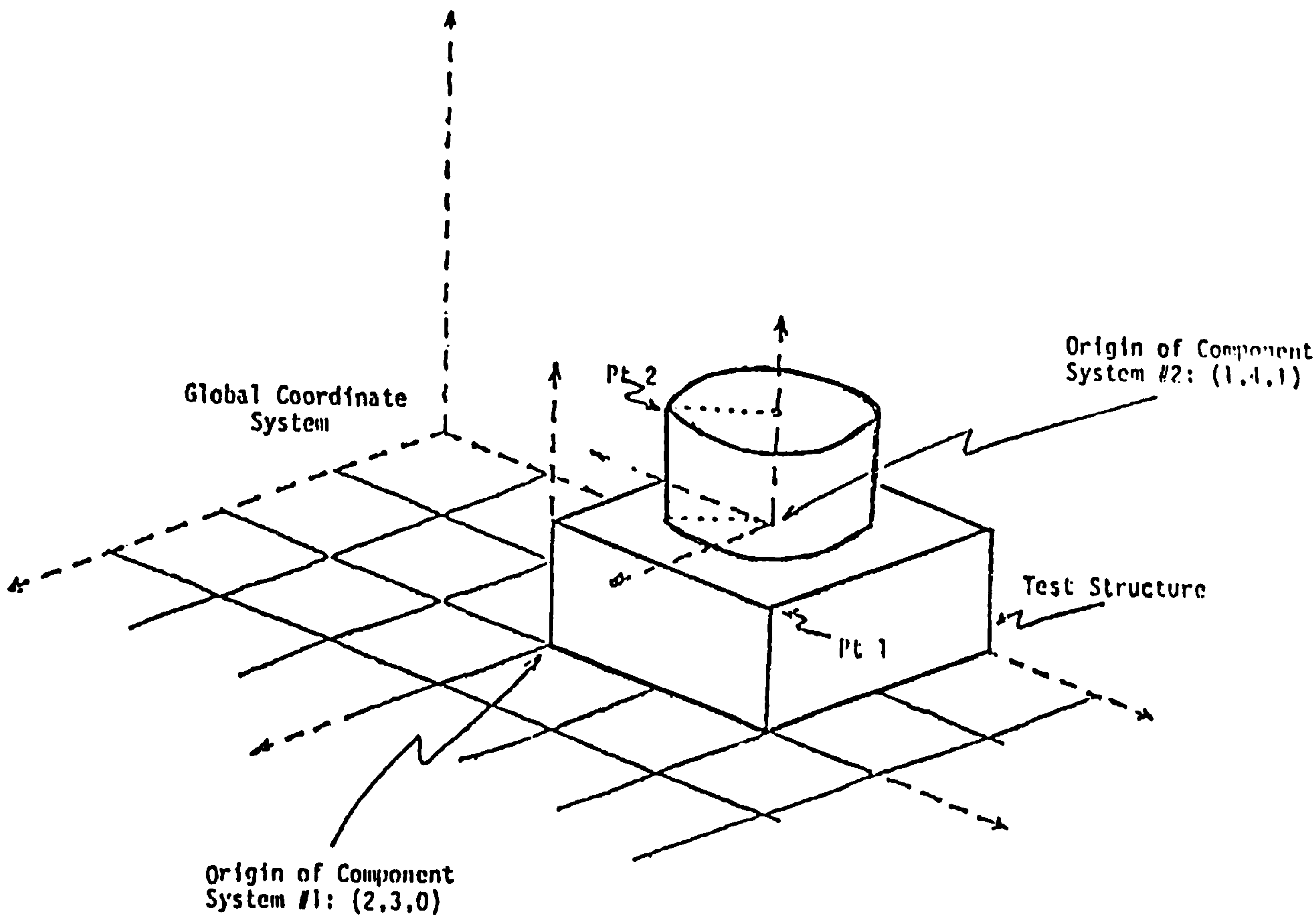


Figure III-1. Example of Component System Definition

Next it is necessary to describe the component system axis orientation with respect to the global system axis. All component axes must be co-linear with any one of the global axes so that only three variables are needed to describe the orientation for each component system these variables are denoted IX, IY, and IZ. Each of these variables is either +1, +2, or +3 depending upon which global axis direction coincides with a particular X, Y, or Z component positive axis direction. The convention for determining IX, IY, IZ is easily established by considering the two sample components. For component system 1, the component positive X axis is in the global positive Y (+2) direction (IX = +2), the component positive Y axis is in the global positive Z (+3) direction (IY = +3), and the component positive Z axis is in the global positive X (+1) direction (IZ = +1). For component system 2, the component positive X axis is in the global negative X (-1) direction (IX = -1), the component positive Y axis is in the global positive Z (+3) direction (IY = + 3), and the component positive Z axis is in the global positive Y (+2) direction (IZ = +2).

Now that the component information for this structure has been completely specified, it necessary to enter the coordinates of each point on the structure relative to the components. Any combination of points may be defined to be on any component -- it is most useful, however, to define points lying on a complete physical "substructure" to be on the same component. In our example, therefore, it would probably be most useful to consider points on the "box" in component 1, and points on the "cylinder" in component 2.

The coordinates of each point within a component system may be described in either cylindrical or rectangular coordinates, depending upon which description is most natural. (The "coordinate type" is a variable that must be given along with the coorinates for each point). Considering our example, we see that the "box" part of the structure is most naturally described in rectangular coordinates, while the "cylindrical" part of the structure is most naturally described in cylindrical coordinates. Therefore, when describing points on these structure components, we would probably use the corresponding coordinate types for our

description. When cylindrical coordinates are to be used, the following two rules apply:

1)

The Z axis of the cylindrical (r, theta, Z) system should coincide with with the Z axis of the system.

2)

Angle Convention:

Component X axis: theta = 0 degrees

Component Y axis: theta = 90 degrees

Therefore, positive theta is determined by use of the "right hand rule".

Using the above conventions, the coordinate data for two points of interest may be easily described. Point 1, on structure component 1, is described in terms of component coordinate system 1 and rectangular coordinates, so that (X1, Y1, Z1, IC1) = (1, 0, 2, 1) ... (IC, the coordinate type variable, is (0) for cylindrical and (1) for rectangular Coordinates). Similary, point 2 on component 2 is described in cylindrical coordinates as (r2, theta 2, Z2, IC2) = (0.5, 45, 1, 0).

For display purposes, it may at times be useful to define the component origin such that the structure is " broken apart". For example, if the origin of component system 2 in Figure III -1 had been defined to be at (4, 1, 3) rather than (4, 1, 1), the cylindrical portion of the structure would be seperated in the Z direction from the rest of the structure on the display, and the "hidden" corner of the "box" would now be visible. This is simply done since the structure of the Data Setup Section allows the component origins and all other structure information to be altered at any time.

3.3.3 FLOATING POINT DATA

In the Data Setup Section, floating point values entered for the test point coordinates are stored in a data "block floating point" form in a system data block. In the Data Acquisition Section, floating point modal coefficients are also stored in "block floating point" format in system data blocks. This floating point representation increases the system capability compared to a simple integer representation, but has limitations of which you should be aware when operating the system.

Figure III-2 demonstrates the inherent limitation of the system's data block floating point number storage. Test point coordinates ranging from 1 to 10000 were entered into the system (as an extreme case), and were in turn stored by the system in one of the system data blocks. Due to the fact the scaling of this data block is determined by the largest number it contains, it can be seen that the smaller numbers suffer greatly in accuracy compared to the larger numbers. For example, the number 10, three orders of magnitude smaller than the largest number in the block, has incured a 1% error in this representation and becomes 9.91. Smaller number fare even more poorly.

A reasonable rule of thumb is that the coordinate file and the modal coefficient file should differ within the file from the largest to the smallest by no more 2 or at most 3 orders of magnitude to retain full calculational accuracy.

PT	CORRDINATED			COMP	ENTRY	ERROR/ENTRY
1	.58	.58	.58	1	1	4.2E-1
2	1.75	1.75	1.75	1	2	1.2E-1
3	4.67	4.67	4.67	1	5	6.6E-2
4	9.91	9.91	9.91	1	10	9.0E-3
5	19.83	19.83	19.83	1	20	8.5E-3
6	49.57	49.57	49.57	1	50	8.6E-3
7	99.73	99.73	99.73	1	100	2.7E-3
8	199.45	199.45	199.45	1	200	2.7E-3
9	499.80	499.80	499.80	1	500	4.0E-4
10	999.59	999.59	999.59	1	1000	4.1E-4
11	1999.77	1999.77	1999.77	1	2000	1.2E-4
12	4999.14	4999.14	4999.14	1	5000	1.7E-4
13	9999.45	9999.45	9999.45	1	10000	5.5E-5

Fig. III-2 Example of Floating Point Number Storage

3.3.4 DATA SETUP SECTION -- Command Summary

There are five "files" which may be edited and listed using the commands in the Data Setup Section:

File 0 : Test Setup Information

File 1 : Structure Components

File 2 : Structure Coordinates

File 3 : Structure Display Sequence (connectivity)

File 4 : Modal Coefficients

3.3.5 Data Setup Section -- Display Sequence File

The Display Sequence file is a sequence of numbers, each of which represents a point on the structure. The sequence specifies the order in which the structure points are to be displayed and how they are to be connected together (blanking on or off).

Let us consider the simple plate structure of Figure III-3a. After describing to the system the locations of the four points, we now need to decsribe to the system how to display the points. We therefore wish to start at point 1 (arbitrary) and draw a solid line through points 2, 3 and 4, and finally a solid line from point 4 back to point 1. The simplest display sequence which will accomplish this is:

Sequence	Point	
1	1	start at point 1
2	2	solid line to point 2
3	3	solid line to point 3
4	4	solid line to point 4
5	5	solid line to point 1

The display will cycle through this display sequence in the manner shown to produce a display like that of Figure III-3b (identical to that of Figure III-3a).

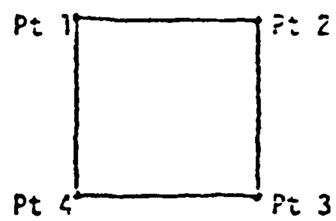


Fig. III-3a. Test Plate

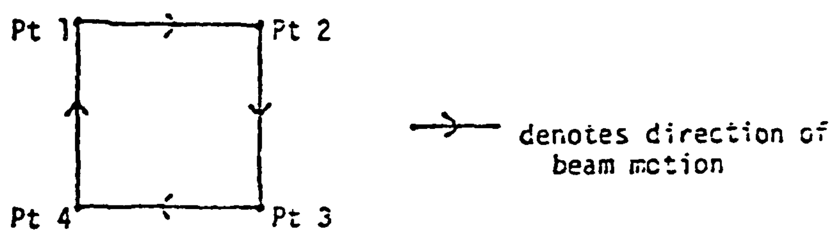


Fig. III-3b. Test Plate Display with Display Sequence File of

#	PT
1	1
2	2
3	3
4	4
5	1

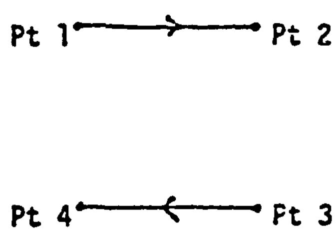


Fig. III-3c. Test Plate Display with Display Sequence File of

#	PT
1	1
2	2
3	-3
4	4
5	-1

If it is desired to "blank" the beam from, say, point 2 to point 3, and from point 4 to point 1 (leaving horizontal lines only) the display sequence file would be:

Sequence	Point	
1	1	start at point 1
2	2	solid line to point 2
3	-3	blank to point 3
4	4	solid line to point 4
5	-1	blank to point 1

Note that, to blank the beam, the end point of the blanking is negative. The display for the above display sequence file would be that of Figure III-3c.

When constructing a display sequence, it is suggested that the following three rules be followed:

1)

If possible, close all possible sequence loops explicitly within the display sequence. If this is not done, confusing displays may result (the deformed and undeformed structure displays may be

2)

Points on the same component should be "grouped together" in the display sequence file, if possible.

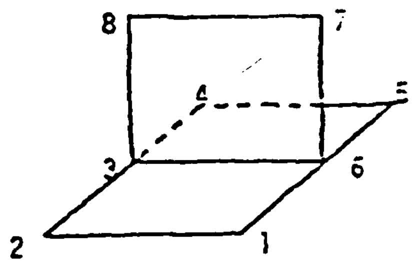
3)

The first point of a component should always be blanked to give correct partial displays by component.

The fact that structure components can be displayed individually (see Chapter 5) must be taken into account when constructing a display sequence file, and adding "dummy" points may be necessary to obtain correct displays in all cases. For

example, consider the "T - Plate" of Figure III-4a, defined by 8 test points. Let us assume the display sequence for the T-Plate is as follows:

Sequence	Point	(Component)
1	-6	1
2	1	1
3	2	1
4	3	1
5	4	1
6	5	1
7	6	1
8	7	2
9	8	2
10	3	1
11	6	1



Pts 1-6: Component 1
(Horizontal Plate)
Pts 7-8: Component 2
(Vertical Plate)

Fig. III-4a. T - Plate

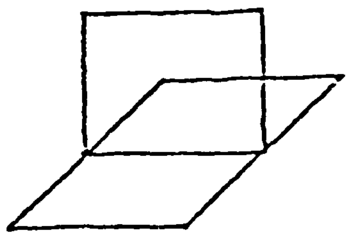


Fig. III-4b. Both Components

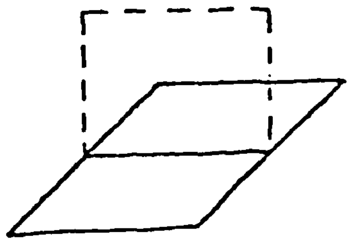


Fig. III-4c. Component 1

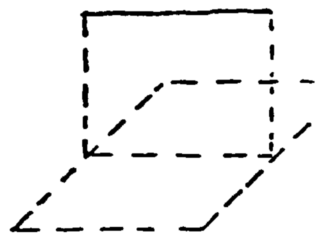
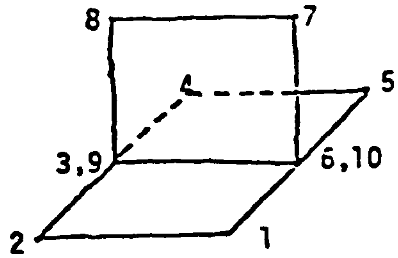


Fig. III-4d. Component 2



Pts 1-6: Component 1
(Horizontal Plate)
Pts 7-10: Component 2
(Vertical Plate)

Fig. III-4e. T - Plate with "Dummy" Points

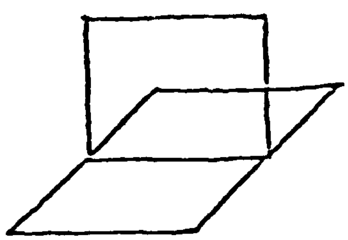


Fig. III-4f. Both Components

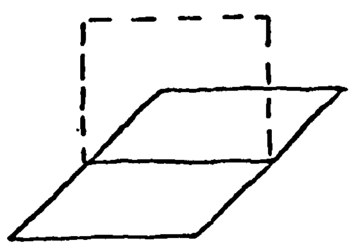


Fig. III-4g. Component 1

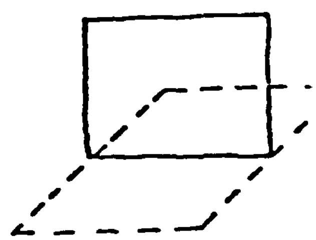


Fig. III-4h. Component 2

Let us also assume we would like to consider the T-Plate comprised of two components, one for the horizontal plate and one for the vertical plate. We therefore define points 1 - 6 to lie on component 1, and points 7 and 8 to be on component 2.

When both components 1 and 2 are displayed, the desired display of Figure III-4b results. However, when only one of the two components is displayed, the display sequence entries for points on other components are effectively non-existent. When component 1 alone is displayed, this is of no consequence as Figure III-4c shows however, the display of component 2 alone is incomplete due to the missing lines formerly provided by the simultaneous display of component 1 (Figure III-4d).

Figure III-4e shows the T-Plate redefined with dummy points 9 and 10, defined to be in the same locations as points 3 and 6 except on component 2 rather than component 1, included.

The correct display sequence would now be:

Sequence	Point	(Component)
1	-6	1
2	1	1
3	2	1
4	3	1
5	4	1
6	5	1
7	6	1
8	-10	2
9	7	2
10	8	2
11	9	2
12	10	2
13	-3	1
14	6	1

The new displays are shown in Figures III-4f, III-4g, and III-4h which display the structure and its components as desired.

The above display sequence file happens to be a good example of a display sequence following the rules given above that is, all sequence loops (there are three -- one for each component seperately and one for the two components combined) are explicitly closed, and the points defining components 1 and 2 are "grouped together" in the file. To illustrate what happens if these rules are not followed, you should consider the the following display sequence file for the T-Plate of Figure III-4e:

Sequence	Point
1	6
2	1
3	2
4	3
5	8
6	7
7	6
8	5
9	4
10	9
11	10
12	6

and why it would be unsatisfactory for displaying only one T-Plate component at a time.

3.3.6 Data Setup Section -- Monitor Commands

Note: () denotes optional parameters

3.3.7 KEYBOARD - K 3

K 3 *** KEYBOARD BUTTON ***

This command is used to enter the Display Sequence Monitor.

This is a very inportant input and great effort has been spent on trying to automate the connectivity file. The maximum number of connections cannot be greater than 500.

In this mode, a secondary monitor is used to input the connectivity. This monitor is denoted "C" and uses the following commands for input:

3.3.8 COUNT -

N1 *** COUNT BUTTON ***

This command can be used to reset the counter to the value N1. The counter is the number of the last display vector (connectivity) entered. If a new display sequence is ever required, the old connectivity file can be eliminated by setting the counter to zero (N1 = 0). The connectivity file is stored using line numbers with one line number per vector (the vector is the ending point number of the beam trace).

3.3.9 KEYBOARD - K

K *** KEYBOARD BUTTON ***

The Keyboard command is used for entering the connectivity file.

After the K command is issued, the computer waits for input N1 and N2 can be entered. If N2 is greater than N1 in the connectivity file, the counter is incremented and the connectivity from N1 to N2 is sequentially stepped. If N2 is defaulted, the N1 value is added to the connectivity file and the counter is incremented. If N2 is less than N1 the

connectivity is incremented from N2 to N1. This input is terminated by inputting zero (0) for N1.

If it is desired to move from point A to another point without drawing a line, N1 should be equal to a negative of point B.

Line numbers are automatically calculated and updated by way of the counter. Termination returns the user to the Display Sequence monitor.

3.3.10 DELETE - /D

/D N1 (N2) *** DELETE BUTTON ***

This command will delete the connectivity file from counter N1 to N2. If N2 is defaulted then N1 will be deleted.

3.3.11 INSERT - /I

/I N1 *** INSERT BUTTON ***

This command will insert after counter value N1. After the /I N1 command is input, then the computer will wait for an input where N2 in entered. The value N2 will be entered into the connectivity file. Additional values can be entered until a zero value is inputted and control is returned to the connectivity file monitor. Terminate with a 0.

3.3.12 PHOTOREADER - R

R ----- *** PHOTOREADER ***

This command will read a paper tape that has been punched as a result of the print command.

3.3.13 REPLACE - /R

/R N1 --------- *** REPLACE BUTTON ***

This command is used just like the insert command but eliminates line N1 with the first entry.

3.3.14 PRINT - W

W (N1) (N2) ------------- *** PRINT BUTTON ***

This command will write the connectivity file for line number N1 to N2. If N1 is equal to 0, then the complete connectivity file will br listed. If switch register bit 14 is pressed, the output will be aborted. If switch register bit 4 is pressed prior to issuing this command, the output will be to the punch.

3.3.15 RETURN - <

<

*** SUBROUTINE RETURN BUTTON ***

This command will return control to the display monitor.

3.4 DATA SETUP SECTION - I/O DEVICES

The I/O device selection in the Data Setup Section is controlled by Switch Register bits 4, 5, 6, and 8.

Input: On input, the input device for the data entered is determined by bit 5 or bit 8 as follows:

Bit 5	Bit 8	INPUT DEVICE
OFF	OFF	TERMINAL
OFF	ON	MAG TAPE, if available
ON	OFF	PHOTOREADER, if avail.
ON	ON	PHOTOREADER, if avail.

Output: On output, the output device is determined from bit 4 and bit 6 as follows:

Bit 5	Bit 6	OUTPUT DEVICE
OFF	OFF	TERMINAL
OFF	ON	LINEPRINTER, if avail.
ON	OFF	PUNCH, if avail.
ON	ON	PUNCH, if avail.

PARAMETER ESTIMATION	CHAPTER 4

4.1 OVERVIEW

The Parameter Estimation Section of the modal system is designed to obtain, automatically, data from file one of the mass storage area of the disc, check to determine if the data belongs to the current data set, and use one of four parameter estimation techniques to determine the real or complex modal coefficients. The four estimation techniques available are as follows:

1) Amplitude (single degree of freedom)

2) Quadrature (single degree of freedom)

3) Kennedy-Pancu circle fit (single degree of freedom with constant residual)

4) Linear least squares (multiple degree of freedom with residual mass and stiffness)

A linear least square time domain program to calculate global frequency and damping values is available to all four techniques but is required for only the last technique. This eigenvalue algorithm involves multiple measurements in the calculation of frequency and damping to be used for residue estimation.

4.2 MEASUREMENT NOTES

In order to identify the modes of vibration of a structure, it is necessary that frequency response data be measured on the structure in such a way that the resulting data is sufficient to identify all modes of interest at all points of interest. The Modal System requires that these measurements be made between a fixed "input" point (the point at which the force is applied) and multiple "response" points (the point at which the response to the input force is measured), or a fixed "response" point and multiple "input" points.

The frequency response measurements may be made using transient or random inputs and baseband or Band Selectable Fourier Analysis (ZOOM).The type of structure, testing convenience, and desired quality of the results being the prime consideration in making the choice between them. Any of the "standard" frequency response programs documented in the 5451 Operating Manual may be used, or modified to measure the required data, in addition, these programs may be supplemented by the use of Y 5, and Y 6 (ADC overload, and number of channels check). Coreload number 1 contains the 5451C software that allows measurements to be made using the 54420 DAC, and the 54470 Preprocessor (Zoom). Y 88 is also part of this coreload and is used to store the measured data to the disc with the proper information so the data can be used by the Modal System (coreload 0). Y 90 is also used in conjunction with Y 88 and both of these are described elsewhere in this manual.

4.3 EIGENVALUE ESTIMATION

The task of determining damped natural frequencies can be performed one of three ways:

1) Manually (channel Number)

2) Cursor (channel Number)

3) Least Squares Eigenvalue (frequency and damping)

With the first two methods, only one piece of data can be used at a time. Therefore, it is wise to scan at least one frequency response function from all major structure components so that no important modes are inadvertantly missed. Operation of the cursor automatically stores the channel number and frequency with the designated mode.

With the third method, a linear least squares time domain method based upon complex exponentials is used to determine the exact damped natural frequency and damping rate. This process can involve any and/or all of the measurements taken. The nearest channel number and a calculation of bandwidth (number of channels on each side of the center frequency) is also performed to allow for any method of residue estimation.

4.3.1 EIGENVALUE - MANUAL

With this method, a data record of representative data will be requested followed by a request for mode and bandwidth. After this, the channel number can be entered from the terminal. (some valid data must be in block zero in order for the frequency calculation to be correct). No information concerning damping is utilized.

Once the information is stored, the mode number and bandwidth question will be repeated. To exit, a mode number of zero is entered.

4.3.2 EIGENVALUES - CURSOR

In this method, a request for a representative data record is the first question asked, followed by the mode number and bandwidth. Again, damping information is not calculated or utilized.

After this data is inputted, block zero is displayed with the cursor superimposed. The switch register is used to control the cursor:

Switch 7 is fast right

Switch 8 is step right

Switch 13 is fast left

Switch 12 is step left

Switch 11 is expand around cursor position

Switch 9 returns data to computer

Switch 6 resets cursor to zero channel

Switch 5 aborts the cursor and returns a zero channel number for the currently requested mode

Once data has been returned to the program a new mode number is requested. When finished, a mode number of zero is entered.

4.3.3 EIGENVALUES - Linear Least Squares Time Domain

This method allows the calculation of eigenvalues for the system in certain frequency ranges of interest. So, a first request will be for a representative data record, followed by some questions of starting channel (manual or cursor entry) and number of channels in calculation. The range of interest is defined by starting channel and number of points to be used

(64, 128, 256).

Because the method uses a great number of measurements, one must enter the first and last record of data to be taken into account, as well as the approximate number of measurements in the range.

4.4 RESIDUE - ESTIMATION

At the present time, the Modal System is capable of estimating complex modal coefficients with the limitation of magnitude resolution of 1 in 2000 and phase resolution of 1 in 10. The ability to animate a display is limited, though, to real modes. With this in mind, the parameter estimation techniques are as follows:

1) Amplitude - The magnitude and phase of a given frequency is recorded. The frequency can be chosen manually, with the cursor, or with the "starting value algorithm".

2) Quadrature - The value of the quadrature, or imaginary, part of the data at a specified frequency is recorded as the magnitude and the angle is assumed to be 90 degrees. The frequency can be chosen manually, with the cursor, or with the "starting value algorithm".

3) Kennedy-Pancu Circle Fit - The Modal System identifies modal coefficients from measured frequency response data by fitting circles in the complex-frequency (or argand plane) through the points centered at a mode's natural frequency and a number of data points on either side of the center channel.

   The magnitude is determined from the diameter of the fitted circle while the phase is determined in a similiar manner as in method one but a "displaced origin" is utilized to eliminate effects of other modes. The frequency can again be chosen manually,

with the cursor, or with the "starting value algorithm".

4) Linear Least Squares Frequency Domain The Modal System executes a least squares error estimation of the data within a 64-128-256 data channel range based upon a frequency domain model of a multiple degree-of-freedom system. The process is linear since the starting values of frequency and damping are not allowed to change from measurement to measurement. The results are the complex residues for the measurement. The model is based upon the following equation:

$$H(ij) = \sum_{r=1}^{N} \frac{A(rij)}{S - P(r)} + \frac{A(rij)^*}{S - P(r)}$$

Where
A(r) = Complex residue
A(r)* = Complex conjugate
P(r) = a(r) + j w(r) = Eigenvalue
w(r) = Damped natural freq.
a(r) = Damping coefficient

4.5 COMPARISON OF TECHNIQUES

The choice of parameter estimation technique depends upon the system being tested. Each technique assumes certain characteristics and will not work well when these conditions are not met.

The amplitude and quadrature methods are limited since they use frequency response values at only one frequency for each mode. This is a rapid and straight forward process which is the basic attraction of these methods. In cases of close modes or high damping, the effects of nearby modes are not eliminated,

thereby giving non-unique modes. Additionally, the finite resolution gives rise to potentially large errors if the damped natural frequency is not described correctly.

To provide more sophistication, the circle fit method can be used to improve points in the neighborhood of the damped natural frequency. This gives better results as long as a mode is present in the argand diagram (that is, not at a node).

Again, resolution can be a problem (as well as noisy data), but better accuracy can be obtained compared to the first two methods. Even so, if the mode coefficient becomes zero or if modes are highly biased or coupled, this method will give confusing results and require manual control of the fit. When run automatically, the speed is not objectional but when run manually, the lack of speed becomes a problem.

In the situation where the first three methods fail, the linear least squares frequency domain fit will provide some success. This technique involves a multiple degree of freedom frequency domain model to generate estimates of residues based upon fixed values of frequency and damping in modes present within a frequency range. To account for effects of modes below the minimum frequency, a residual mass term (function of the inverse of frequency squared) is included. Likewise, to account for modes above the maximum frequency a residual stiffness term (complex constant) is included. Using this approach, closely spaced modes of vibration may often be seperated.

4.6 CIRCLE FIT PRESENTATION

After a circle fit is computed for a mode, the system displays the following waveforms on the 5460 display screen:

1) The circle fit for the present mode (this is only

displayed with the 5460 switch in the COMPLEX position

2) The data center channel and (BW + 15) data points on either side of the center channel (if they exist).

3) (intensified). The data center channel and (BW) data points on either side of the center channel (if they exist).

The data points may not exist for display, for example, if the center channel of a mode was channel 5 and the bandwidth was 2. In this case, the display of (2) above would extent from data channel 0 to channel 22.

If the mode center channel is near either end of a data block, the system will use as many points as possible up to the normal limit to calculate the circle fit and display the results.

The circle fit display is used to judge the acceptability of the circle fit and, hence, the accuracy of the modal coefficient determined from it. In general, the data points should lie near or on the circle. Due to the finite resolution, the points may not be evenly spaced on the circle, especially for very lightly damped modes. A "typical" circle fit display (for BW = 2) is shown in Figure IV -1.

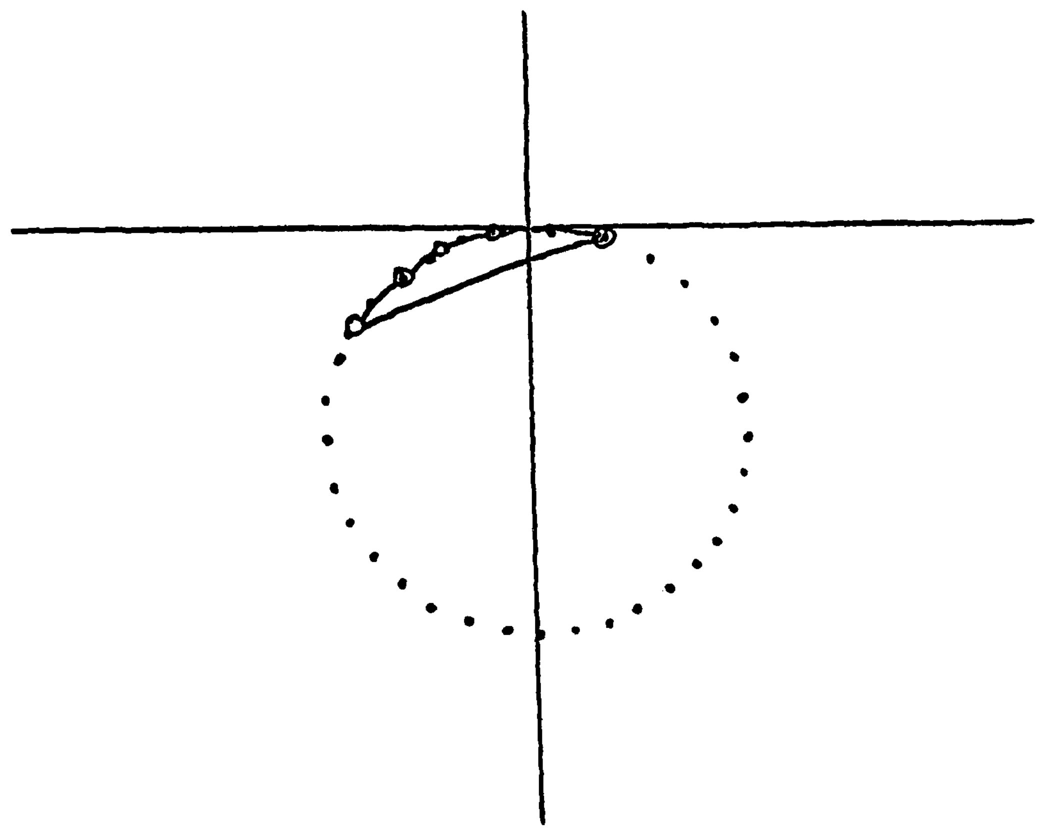


Fig. IV-1. "Typical" Circle Fit Display (for BW=2)

4.7 PARAMETER ESTIMATION - Command Summary

Note: ( ) Denotes optional parameters

4.7.1 ADD - A+

A+ *** ADD BUTTON ***

This mode of operation is primarily conservational. Seperate sub-monitors are available for circle fit, starting value algorithm, and linear least squares frequency domain parameter estimation.

The system prompts with a request to enter the option to be used to determine the frequencies and damping as follows:

1) MANUAL
2) CURSOR
3) LEAST SQUARES ESTIMATE
4) CURRENTLY SELECTED VALUES
5) RETURN TO MONITOR

The most common entry is Least Squares Estimate, and it can be used with any method to determine the modal coefficients.

4.8 LEAST SQUARES EIGENVALUE - COMMAND SUMMARY

This monitor is conversational, and it will prompt the operator as to the disc record number of typical test data and whether the choice for the starting channel is a manual or cursor entry.

It will also ask the number of points to be used in the parameter estimation (typically 128), and it will ask the range of disc records to be used to determine the frequencies and dampings.

After answering the above question, the system will search all disc records with the 5460 nixie display indicating which measurement it is currently working with. It will then print out a list of the Least Squared Error as a function of the number of degrees of freedom. At this point, the " SP " command is used to specify the number of degrees of freedom to be used. Typically one looks for the number of degrees of freedom where the Least Squared Error has reached a "minimum" where more degrees of freedom does not significantly further reduce the error.

One then uses the " D " and " CL " commands to view where the modes are relative to a typical measurement display. Modes can be deleted using the " /D " command, and the revised list of modes can be printed with the " W " command.

When the number of modes preserved are what is desired the Eigenvalue program is exited using the " < " command. At this point the system prompts the operator to pick the method to be used to determine the modal coefficients. The options are as follows:

1) MAGNITUDE
2) IMAGINARY PART
3) REAL PART
4) KENNEDY-PANCU CIRCLE FIT
5) LEAST-SQUARES FREQUENCY DOMAIN
6) RETURN TO MONITOR

4.8.1 POWER SPECTRUM - SP

SP N1 *** POWER SPECTRUM ***

This command calculates the relative least squares error for degrees of freedom N1. In the automatic mode, N1 = 32. If N1 = 0, an interactive mode requests the range of degrees of freedom N1 to N2.

If N1 is a value in the range of 2 to 40, the error as well as the realistic modal parameters are printed out.

The value of N1 cannot be defaulted.

4.8.2 DELETE - /D

/D N1 *** DELETE BUTTON ***

This command deletes the modal parameters for mode N1 from the list of modes created by a " SP N1 " command. The modal parameter list is immediately renumbered.

4.8.3 CLEAR - CL

CL N1 *** CLEAR BUTTON ***

This command clears the channel(s) nearest to the

calculated damped natural frequency(s) and then performs a Log Magnitude calculation of the frequency response function. The command give visual identification as to the location of the damped natural frequencies with respect to the peaks in the composite power spectrum display.

If the clear command is given a second time the cleared channels go to the top of the screen instead of the bottom of the screen.

4.8.4 DISPLAY - D

D (No Parameters) *** DISPLAY COMMAND ***

Calculates a magnitude display of the composite power spectrum data to be used for visual identification of the location of the damped natural frequencies.

4.8.5 PRINT - W

W (No Parameters) *** PRINT BUTTON ***

This command prints the current values of the modal parameters to the output device as selected by the switch register.

4.8.6 RETURN - <

< (No Parameters) *** SUBROUTINE RETURN BUTTON ***

This command returns to the parameter estimation logic to allow the residues to be estimated based upon the current list of starting values. If too many starting values have been identified, the values must be reordered according to importance or some must be deleted.

4.9 LEAST SQUARES RESIDUES - COMMAND SUMMARY

The system will prompt the operator to clear the current modal coefficients (enter a 0 to clear or a space not to clear). It will then ask which option is to be used for the residual terms. It then asks whether an interactive or automatic mode is desired (typical response is automatic). The next question asked is the range of disc records to be used for the current test. There are some switch register options listed at this point, the most common one is bit 2 which is useful for a printout of the modal parameters. The system will then begin fitting each measurement and displaying in a front-back mode the data versus the fit. To continue on to the next measurement a " D -1 " or a " -1 " is entered on the terminal.

4.10 LEAST SQUARES RESIDUES - AUTOMATIC MODE

4.10.1 DISPLAY - D

D N1 N2 *** DISPLAY BUTTON ***

This command is used to display channels N1 through N2 of the raw and theoretical data in a front to back format. To

exit the display, an integer number N1 is entered. If N1 = 0, this measurement is skipped and the next measurement in the range is read from the disc. If N1 < 0, the data is saved and the next measurement is is processed.

4.11 LEAST SQUARES RESIDUES - INTERACTIVE MODE

In this mode a double asterisk (**) is displayed as the monitor prompt character.

4.11.1 MASS STORE - MS

MS N1 N2 *** MASS STORE BUTTON ***

This command operates the same way as the Fourier system command. It is used to store the modal data to the disc.

4.11.2 PRINT - W

W (no parameters) *** PRINT COMMAND ***

This command prints out the modal parameters of mode number, frequency, damping (zeta), and the magnitude and phase along with the real and imaginary parts of the residue.

4.11.3 CURVE FITTING - CR

CR (no parameters) *** CORELATION BUTTON ***

This command calculates a set of residues for the starting values for a measurement. The range of measurement locations on the disc is input interactively so that, after each calculation is accepted, the next measurement in the range will be processed.

4.11.4 RECONSTRUCTION - CV

CV (no parameters) *** CONVOLUTION BUTTON ***

This command takes the results of the residue calculation and forms thr mathematical frequency response function for display verification. It is usually called right after the CR command.

4.11.5 RESIDUE CONSTRUCTION - SP

SP N1 *** POWER SPECTRUM ***

If N1 is less than or equal to 0, a set of starting values can be entered.

If N1 is greater than 0, the residue calculation begins as in the CR command but no data is read from the disc. The data is assumed to be in block 0.

4.11.6 DISPLAY - D

D N1 N2 *** DISPLAY BUTTON ***

This command is the same as that found under automatic option.

4.12 CIRCLE FIT MONITOR

The Circle Fit Monitor allows you to interactively change the circle fit or the coefficient (the monitor character " D " is printed).

The values of center channel and bandwidth are considered "permanent" values. When you first fit a mode using the command, these permanent values are assigned to "temporary" or "working" values from which the circle fit is calculated. The circle fit is always calculated from these "temporary" values of center channel and bandwidth.

The Circle Fit commands allow the "temporary" center channel and bandwidth to be varied in order that the circle fit for a mode may be improved. Whenever new circle fits are calculated, a new modal coefficient is found. When you judge the fit or the coefficient to be acceptable, the coefficient may be saved. In addition, the new "temporary" center channel and bandwidth may be saved as the "permanent" values in the table, so that they will be used as the "temporary" values for this mode in later measurements.

Additional Circle Fit commands allow a "temporary" estimate of damping for the current mode to be made if desired, this "temporary" estimate may be stored into the table, or the table value may be recalled to become the "temporary" value.

4.13 CIRCLE FIT COMMAND SUMMARY

Note: ( ) denotes optional parameters

4.13.1 N1 TEMPORARY BANDWIDTH

N1 Assign New ("temporary") bandwidth

Assign the value of N1 (1<N1<30) to the "temporary" bandwidth for the current mode, and recalculate the circle fit using this new bandwidth value. N1 = 0 uses the quadrature response and proceeds. N1<0 accepts the current circle fit.

The bandwidth refers to the number of data points to be included in the circle fit. A bandwidth of "1" uses the center channel plus and minus one channel.

4.13.2 ROTATE -

Assign New Center Channel *** ROTATE BUTTON ***

Increment the current "temporary" center channel value by value N1 (+ or -) and recalculate the circle fit.

4.13.3 SUBSTRACT - A-

A- Recall Old Center Channel *** SUBSTRACT BUTTON ***

Assign the center channel value from the table to the "temporary" center channel, print the value, and recalculate the circle fit.

4.13.4 CLEAR - CL

CL Clear Coefficient *** CLEAR BUTTON ***

Sets the modal coefficients to zero and proceeds.

4.13.5 REPLACE - /R

/R Save "temporary" values *** REPLACE BUTTON ***

Save the "temporary" values of center channel, bandwidth, and damping into the table, thereby making them the "permanent" values for the current mode.

4.13.6 MISC. INFORMATION

Automatic Circle Fit (Bit 1)

If switch register bit 1 is on when the algorithm is entered, the coefficeints from the modal circle fits will automatically accepted with no circle fit displays or user interaction.

Suppress Printout (Bit 15)

If switch register bit 15 is on, the printout of point number and orientation will be suppressed.

At the completion of processing the range of measurements requested, the system returns from the circle fit monitor (D) to the Y 9 monitor (*) where one could then ask for the animated displays, etc.

DATA DISPLAY	CHAPTER 5

5.1 OVERVIEW

The Data Display Section of the Modal System is entered by typing 'Y 9' on the system TTY. The program will then respond by printing a "*" on the TTY signifying that the "*" monitor is now in operation.

This section outlines the Data Display commands available. Once the necessary steps of the Data Setup and Data Acquisition sections have been performed, these commands allow you to obtain animated mode shape displays for the test structure.

5.2 CONSTRUCTING THE DISPLAY

Note that, as the display is being constructed, data blocks 0 and 1 are being used to store various 'working' arrays of display points. As long as the contents of these blocks remain intact, the program will display the animated mode shape whenever the "*" monitor is active. If the "*" monitor is exited via a command and then later re-entered by calling 'Y 9', the animated display will appear provided blocks 0 and 1 are intact. When blocks 0 and 1 are filled, a flag is written. When the "*" monitor is exited and then re-entered the system checks to see if this flag is there. If block 0 has been destroyed or altered, the flag will probably have been altered also - if this is the case, the system will not display on the screen when the "*" monitor is active until another command is

given which constructs a display. Of course, it is possible to alter the contents of blocks 0 and 1 without altering the flag – in this case, the display that you see when the "*" monitor is re-entered will be erroneous and system errors may occur.

5.3 AXIS ORIENTATION

The global coordinate system for display purposes is assumed to be:

```
              Y

              +
              +
              +
              +
              +
              +
              +
            +   +
          +       +
        +           +
      +               +
    +                   +
  Z                       X
```

The system resolves coordinates and deformations in the three global directions shown above into the display two-dimensional system.

```
    Y

    +
    +
    +
    +
    +
    +
    +
    + + + + + + + +   X
```

5.4 SCALING CONSIDERATIONS

The working arrays of points stored in block 0 and 1 are defined relative to the display X-Y coordinate system.

Ultimately, all structure coordinates and motion are broken down into coordinates and motion within this X-Y system.

The display calculation will automatically scale to 80% of the 5400 display unit, with the display switch in the Complex Mode. In this position only the left portion (8 x 8) of the total display (10 x 8) is utilized.

5.5 When to use the Data Display Commands

Although some care has been taken to make the Data Display Commands usable at any time, it is recommended that these commands be used only after performing the Data Setup for the structure acquiring modal coefficients through the Data Acquisition process. Using the Data Display commands at times when valid data does not exist will produce neaningless results or possible system errors.

5.6 Initialization of Display Parameters

Whenever the "*" monitor is entered by typing 'Y 9', display parameters controlling the following functions are initialized to

```
Deformation Amplitude
Display Expansion      (80% of maximum)
Display Rotation       (no rotation)
Horizontal Position    (to center of display)
Vertical Position      (to center of display)
View Position          (to (1,1,1) )
"Still" Function       (display undeformed shape)
                          plus animation)
```

The various Data Display commands are capable of changing all of the above parameters for the purpose of modifying the display. The system "remembers" the values of parameters controlling the display functions even though the modes or components being displayed may change. These parameters may be "reset" to default values either by exiting and re-entering the "*" monitor (which resets all except animation speed) or by entering the appropriate Data Display command with no parameters (this resets only the parameter for that command). In this matter, the position (for example) of the animated display display will never be changed once it has been set unless a specific command is given to restore the default display position.

5.7 Command Summary

Note: ( ) denotes optional parameters

5.7.1 PRINT - W

W N1 (N2) (N3) (N4)   *** PRINT BUTTON ***

N1 = 0 The test set-up is printed.

N1 = 1 The component data from N2 to N3 is printed.

N1 = 2 The geometry data from point N2 to N3 is printed.

N1 = 3 The connectivity file from N2 to N3 is printed.

N1 = 4 Mode frequencies and damping is printed.

N1 = 5 The modal coefficients from mode N1 from point N3 to N4 is printed. Note N2 cannot be defaulted if N1 = 5.

If N1 = 2, 3, 4, or 5 and switch 14 is pressed the output will be aborted.

5.7.2 STORE X<

X> (N1) *** STORE BUTTON ***

This command will store the set-up and modal coefficient which then can be loaded later. N1 specifies the record number where the information is written. The next available record will be reported. (0 < N1 < 800)

5.7.3 LOAD X<

X< (N1) *** LOAD BUTTON ***

This command will read the store command. N1 specifies the record number.

5.7.4 CONVOLVE - CV

CV N1 *** CONVOLUTION BUTTON ***

This command controls the display rate of the display The larger the value of N1 the slower the display. Typical values are in the range of 1 to 10. For displays with a very few number of points little control of the display rate will be possible.

5.7.5 DIVIDE - : (or EX)

: (or EX) N1 *** DIVIDE BUTTON ***

This command will expand the view by the percentage N1.

5.7.6 TRANSFER FUNCTION - CH (or AM)

CH (or AM) N1 *** TRANSFER FUNCTION BUTTON ***

This command will expand the amplitude of vibration by the percentage N1.

5.7.7 SUBSTRACTION A- (or R)

A- (or R) N1 *** SUBTRACTION BUTTON ***

This command will rotate the view by an angle equal to N1 degrees. Default of N1 is approximately 81 degrees.

5.7.8 DIFFERENTATION - % (or V)

% (or V) (N1) (N) (N3) (N4) *** DIFFERENTIATE BUTTON***

This command changes the viewing position where N1, N2, and N3 are the X, Y, Z coordinates of the viewing position with respect to the global coordinate system. If N4 is input, only the transformation matrix is recalculated. A new display will not be calculated. (Default N1 = N2 = N3 = 1)

5.7.9 POWER SPECTRUM - SP

SP N1 *** POWER SPECTRUM BUTTON ***

This rescales the initial display upon entering a new mode so that the display fills the CRT screen. A typical value for N1 is 3400.

5.7.10 DISPLAY - D

D (N1) (N2) (N3) (N4) (N5) (N6)   *** DISPLAY BUTTON ***

This command is used for displaying the mode shape data. N1=0 or positive, mode N1 will be displayed, where N1 = 0 is the undeformed mode shape. All components will be displayed as long as N2 is defaulted. If N1 is positive, mode N1 will be displayed for N2 number of components with components N3, N4, N5, and N6 being displayed. A display command with all parameters defaulted, stops the display or removes the undeformed geometry. It works in a cyclic fashon, with the first entry stopping animation, second entry removing undeformed geometry with animation, third stopping animation and the fourth entry replacing undeformed geometry, which was the initial condition. If N1<0, the mode will be completely recalculated even if the requested mode is currently being displayed.

5.7.11 ROTATE (or M)

M N1 N2 (or rotate key)   *** ROTATE BUTTON ***

The move command will move the display so that the point N1 is centered in the display screen If N2 is given then the display will shift N1 percent to the right and N2 percent up. Negative is left and down.

5.7.12 INTERROGATE - ?

? (N1)   *** INTEROGATE BUTTON ***

70

This command is used to intensify a point being currently displayed. Ni is the point number to be displayed. If Ni=0, (default) the intensify function is turned off.

5.7.13 SUBROUTINE - <

< *** SUB-RETURN BUTTON ***

This command returns control to the Fourier monitor.

DATA PRESENTATION	CHAPTER 6

6.1 OVERVIEW

This section of the Modal System is intended to facilitate the process of making a formal report or graphic record of modal data either in plotted or animated form. Most features are designed to work with an HP - 7210 plotter, HP - 9872 plotter or a Tektronix 4012 terminal interchangeably. Software has been implemented which can locate the proper I/O slot so that a particular configuration is unnecessary. In the plotting mode, any deformed or undeformed position can be presented (with the undeformed shape, the data points can be annotated and the lines can be dotted). Labeling is available at any time. Of particular interest to videotape or movie presentations is the capability of displaying alphanumeric titles to the HP 5460 Display CRT.

6.2 DATA PRESENTATION COMMANDS - USE

Data Presentation Commands can be executed at any time although, if sufficient data is not available, an error message will result. In general, if a request has been made to plot a Mode Shape or annotate a plotted mode shape, an animated display must be available. Displaying titles on the HP 5460 Display unit can be done at any time.

6.3 DATA PLOTTING - COMMAND SUMMARY

NOTE: ( ) denotes optional parameter

6.3.1 ANALOG OUT - B

B (N1) (N2) *** ANALOG OUT BUTTON ***

This command is used to plot the mode shape currently being displayed. For N2 = 0 (default), the undeformed shape is plotted. For N2 = 1 - 20 the deformation position (1 - 20) is plotted. If N1 = 10 plot will be to the HP 7210. If N1 = 6 plot will be to the HP 2648 terminal. If N1 = 37 (default), plot will be to the HP 9872 or the 7245 digital plotter. The undeformed shape is normally in dotted format. If solid lines are required, switch 12 on will give solid lines. The points can be labeled if a point command has been issued prior to the solid line undeformed shape plot. When using the 2648 Terminal or the Tektronic 4012, switch 15 on will abort the auto erase between plots.

If N2 is negative, a plot of 10 positions of the deformed shape will be generated to device N1.

6.3.2 LABEL - L

L (N1) (N2) (N3) (N4) *** LABEL BUTTON ***

This command is used to label the plot. The label size and position is controlled as follows:

N1 = device
 = 10 for HP 7210
 = 37 for HP 9872

N2 = (default = 50) = X starting position

N3 = (default = 700) = Y starting position

setup will then be restored to the disc.
(N4 default value = none

Upon issuing the Y 88 N1 (N2) (N3) (N4) command the program will respond with a prompt character " D " on the terminal. The user must then enter the point number and transducer orientation as such:

N (IX) (IY) (IZ), where:

N = Point number associated with current measurement.

IX = Transducer orientation associated with data in block 1.

IY = Transducer orientation associated with data in block 2.

IZ = Transducer orientation associated with data in block 3.

Transducer orientations are expressed as integers of -3, -2, -1, 1, 2, or 3 corresponding to local coordinate directions -z, -y, -x, x, y, z respectively. The correct orientation entry is that which describes the local direction in which the transducer is pointing.

The direction of the transducer can be imagined by drawing a vector from the base of the transducer through the top of it. As an example, if the transducer associated with the data in block 1 is pointing in the positive local Y direction then IX = 2.

If successive measurements have the same transducer orientation then switch register bit 1 may be turned on to have automatic incrementing of the point number. If switch register

N4 = (default = 200) = width and height of characters (HP 7210)

N4 = (default = 1) = Pen Number (HP 9872)

After the command is entered, the label is entered on the terminal. Further lines may be entered below the first line after the first line has been output to the device. This mode is exited by the Terminate Button (/).

6.3.3 POINT - /.

/. (N1) (N2) (N3) (N4) (N5)   *** POINT BUTTON ***

This command is used to enable the plotting of point numbers on the undeformed, solid line plot (switch 12 on). N1 is the X offset, N2 is the Y offset, and N3 is the character size. Default values for all three parameters are 100. This feature has been implemented only on the HP 7210 plotter and the HP 9872 plotter. Switch 13 will abort only the labeling. If N4 and N5 are entered, only those point numbers between N4 and N5 will be printed.

6.3.4 LIST - /L

/L (N1) (N2) (N3)   *** LIST BUTTON ***

This program executes a call to subroutine similiar to User Program 7074 (Reference Chapter 9) which displays ASCII text to the HP 5460 Display Unit for use as titles in video-taping or movie-making.

N1 = 0 Title will be entered manually

N1 > 0 Automatic display of the frequency for mode number N1

N1 < 0 Disc record (-N1) where previously constructed titles have been stored.

N2 = Character size (N2 x N2) a value of 1000 yeilds a character size of 1 cm by 1 cm.

N3 = Y position of starting line of text (-32000 to 32000).

The X position of each line of text is automatically centered.

Default values: N1 = 0

N2 = 500

N3 = 5000

This feature is aborted when any character is entered.

```
+---------------------------------------+------------------+
|                                       |                  |
|   USER PROGRAM  Y 88                  |   CHAPTER  7     |
|                                       |                  |
+---------------------------------------+------------------+
```

This program is called within the data acquisition keyboard program (using the 5451 C software coreload 1) in order to put the proper test ID information into the data block header area when the data is stored to the disc.

The following command formats may be used:

Y 88 5 N1

> Reads test setup from record N1 on the disc (N1 default value is = 19).

Y 88 6 N1

> Writes current core resident setup to the disc record N1 (default value = 19).

Y 88 N1 (N2) (N3) (N4)

> N1 = 1, 2 or 3
>
> > Stores data block 1 through N1 to the disc
>
> N2 = Point number increment value
> (N2 default value = 1)
>
> N3 = Zoom range parameter (N3 = 0 -5)
> (N3 default value = 0 ie, baseband)
>
> N4 = Disc data record number where setup is stored. Setup will be read before storing current data blocks, an updated

bit 0 is off then point number is increased by N2. If bit 0 is on then point number is decreased by N2.

If the parameter N2 is less than or equal to zero the point number is not incremented and the data is stored with the current point number and transducer orientation.

The third parameter, N3, specifies the two character zoom range parameter that will be stored in the header. N3 is an integer from 0 to 5 which specifies a parameter of Z0 to Z5 respectively. The zoom range parameter provides an easy key on which other programs can search when looking for a specific frequency range.

The fourth parameter, N4, specifies the disc data record where the test setup has been stored using Y 90. If N4 is specified then the test setup is read from the disc data record N4 (file 7) before the current data is stored to the disc. After the data has been stored, the test setup is restored to disc data record N4. In this way the test setup always contains the last point number and transducer orientation used. Before the setup is read, the mass store file 1 pointer is kept so that after reading or writing the test setup, the data file pointer is returned to its original location

TYPICAL EXAMPLE "CANNED" DATA	CHAPTER 8

This chapter lists in order, a typical listing of the terminal printout during the operation of the modal software. Indented wordage within brackets are comments not printed by the terminal.

```
MAX BLOCKS #/SIZE/SPACE
       2    2048    4992

Y 90


 UCMIE  TEST SET-UP PROGRAM :  Y 90


@

K

ENTER TEST I.D. :
A/P

ENTER DATE :
040980

ENTER DISC STORAGE START RECORD :
1

@

K 1

ENTER EXCITER POSITION AND DIRECTION : [ INTEGERS ]
1,3
       1 Z

ENTER LOAD CELL MODEL # AND SERIAL # :
101,11

ENTER NUMBER OF RESPONSE DIRECTIONS :
```

```
3

ENTER 3 RESPONSE TRANSDUCER'S
 MODEL NUMBER , SERIAL NUMBER , CALIBRATION NUMBER :
102,1,1
103,2,1
104,3,1

@

K 2

ENTER DATA TYPE CODE (2 CHARACTER) :
AC

ENTER ZERO FOR IMPACT OR ONE FOR RANDOM :
1

INPUT NUMBER OF ZOOM RANGES :
0

@

X>2

@

<

MS38 10

MS18 1
MAX BLOCKS #/SIZE/SPACE
       4/   2048/   8512

Y 9

UNIVERSITY OF CINCINNATI/LEUVEN MODAL ANALYSIS SYSTEM
               VERSION:  NOVEMBER     1979
*
X<708
```

(Here previous data, consisting of components, coordinates, display sequence, etc. are loaded)

```
TEST ID IS                          A/P
*
W

TEST ID IS                          A/P
```

80

```
DATE IS                                04 09 80

NUMBER OF POINTS IS                          39
NUMBER OF MODES IS                           10
*
A+

ENTER OPTION TO BE USED FOR FREQUENCIES AND DAMPING
       1) MANUAL
       2) CURSOR
       3) LEAST SQUARES ESTIMATE
       4) CURRENTLY SELECTED VALUES
       5) RETURN TO MONITOR

3

INPUT DISC DATA RECORD OF TYPICAL TEST DATA:
1

E .TER OPTION FOR CHOICE OF STARTING CHANNEL:
     1) MANUAL
     2) CURSOR

2

SET CURSOR ON STARTING CHANNEL:

      (USE SWITCH 9 ONCE CURSOR IS ON DESIRED
       STARTING CHANNEL)

ENTER NUMBER OF POINTS TO BE USED IN THE PARAMETER ESTIMATION:
     (64,128,256)

128

STARTING FREQUENCY        .18000E+01
CHANNEL    180 TO   308

ENTER 0 TO ACCEPT:

0

ENTER RANGE OF DISC RECORDS FOR CURRENT TEST:(N1,N2,N3)
          N1 = STARTING RECORD
          N2 = ENDING RECORD
          N3 = NUMBER OF SAMPLES/MEASUREMENT (OPTIONAL)
1 46
```

81

```
DOF  2  ERROR =  .188360E+00 @***************************  @
DOF  3  ERROR =  .645750E-01 @*************************    @
DOF  4  ERROR =  .539607E-01 @*************************    @
DOF  5  ERROR =  .312228E-01 @************************     @
DOF  6  ERROR =  .153011E-01 @***********************      @
DOF  7  ERROR =  .371186E-02 @********************         @
DOF  8  ERROR =  .159108E-02 @*******************          @
DOF  9  ERROR =  .973241E-03 @******************           @
DOF 10  ERROR =  .605324E-03 @*****************            @
DOF 11  ERROR =  .232289E-03 @***************              @
DOF 12  ERROR =  .167100E-03 @***************              @
DOF 13  ERROR =  .817006E-04 @**************               @
DOF 14  ERROR =  .392982E-04 @************                 @
DOF 15  ERROR =  .399587E-04 @************                 @
DOF 16  ERROR =  .299855E-04 @************                 @
DOF 17  ERROR =  .262208E-04 @************                 @
DOF 18  ERROR =  .191537E-04 @***********                  @
DOF 19  ERROR =  .118225E-04 @**********                   @
DOF 20  ERROR =  .634055E-05 @*********                    @
DOF 21  ERROR =  .402889E-05 @*********                    @
DOF 22  ERROR =  .445822E-05 @**********                   @
DOF 23  ERROR =  .508565E-05 @**********                   @
DOF 24  ERROR =  .406191E-05 @*********                    @
DOF 25  ERROR =  .422703E-05 @**********                   @
DOF 26  ERROR =  .198142E-05 @********                     @
DOF 27  ERROR =  .241073E-05 @*********                    @
DOF 28  ERROR =  .255934E-05 @*********                    @
DOF 29  ERROR =  .244375E-05 @*********                    @
DOF 30  ERROR =  .213828E-05 @*********                    @
DOF 31  ERROR =  .203096E-05 @********                     @
DOF 32  ERROR =  .190712E-05 @********                     @
**
SP20

DOF 20  ERROR =  .634055E-05 @**********                   @
MODE   FREQUENCY  DAMPING RATIO        ZETA (%)

  1       1.800           .055       3.0654502
  2       1.916           .265      13.7217903
  3       1.918           .017        .8817592
  4       2.107           .040       1.8927138
  5       2.181           .074       3.4007921
  6       2.491           .078       3.1388712
  7       2.597           .095       3.6707439
  8       2.676           .034       1.2614412
  9       2.896           .077       2.6539407
 10       3.080           .206       6.6735630

 11       3.080           .790      24.8577423
**
D
```

82

```
**
CL
**
 /D11
**
 /D10
**
 /D2
**
W
MODE   FREQUENCY   DAMPING RATIO      ZETA (%)

  1       1.800             .055      3.0654502
  2       1.918             .017       .8817592
  3       2.107             .040      1.8927138
  4       2.181             .074      3.4007921
  5       2.491             .078      3.1388712
  6       2.597             .095      3.6707439
  7       2.676             .034      1.2614412
  8       2.896             .077      2.6539407
**
<

ENTER OPTION TO BE USED TO DETERMINE MODAL COEFFICIENTS:
       1) MAGNITUDE
       2) IMAGINARY PART
       3) REAL PART
       4) KENNEDY-PANCU CIRCLE FIT
       5) LEAST SQUARES FREQUENCY DOMAIN
       6) RETURN TO MONITOR

5

ENTER 0 TO CLEAR CURRENT MODAL COEFFICIENTS
0

ENTER OPTION FOR RESIDUAL TERMS TO BE INCLUDED:
     1) NO RESIDUALS
     2) RESIDUAL MASS ONLY
     3) RESIDUAL FLEXIBILITY ONLY
     4) RESIDUAL MASS AND FLEXIBILITY
4

INTERACTIVE(0) OR AUTOMATIC(1)
1

SWITCH 15  ABORT POINT PRINT
SWITCH 14  ABORT PARAMETER ESTIMATION
SWITCH 13  ABORT AUTOMATIC CALIBRATION
SWITCH 11  ABORT NIXIE TUBE DISPLAY
SWITCH 10  SUPRESS SCALING QUESTION
```

```
SWITCH  2  PRINT RESIDUE RESULTS
SWITCH  0  ABORT DATA RECONSTRUCTION

ENTER RANGE OF RECORDS FOR CURRENT TEST:
1 46
Z    1
 LEAST SQUARED ERROR =     .10024E-01
-1
Z    2
 LEAST SQUARED ERROR =     .10405E-01
-1
         (TURN ON SWITCH 0)
Z    3
Z    4
         (THIS CONTINUES FOR ALL MEAS.)


*
D 1


       1.8000 HERTZ
*
```

At this point one could ask for various printouts, display other modes or plot the results. Typically one would also store this analysis to the disc in a typical location like record 720.

Y 7074 - ALPHANUMERIC DISPLAY ON CRT

This program allows the user to generate ASCII characters in a data block for display purposes. It was written with the intention of generating titles, sub-titles and labels for video tapes of mode shapes.

There are 60 characters available, plus the space. The characters are:

A through Z
0 through 9

! " # $ % ' ( ) * - ; = _ T @ : < > , . / ?

The command call is: Y 7074 - LY ISIZE

where: LY is the location of the first character Y-axis

ISIZE is the character size

The screen is divided as shown here:

```
         +32000 +-----------+-----------+*****
                +-----------+-----------+*****
                +-----------+-----------+*****
                +-----------+-----------+*****
                +-----------+-----------+*****
Y-axis        0 +-----------+-----------+*****
                +-----------+-----------+*****
                +-----------+-----------+*****
                +-----------+-----------+*****
                +-----------+-----------+*****
         -32000 +-----------+-----------+*****

             -32000         0        +32000

                         X-axis
```

Note: Characters must be viewed in the COMPLEX plane. Therefore, only an eight division portion of the display is used.

The parameter ISIZE defaults to 400, LY defaults to 0.

ISIZE can range from 32000, but becomes unreasonable past 2000.

Following the command call, the system responds on the terminal with the number of characters available per line without overflow to the next line. This permits the user to calculate positioning of the characters before entry. The system then waits for an input from the terminal of up to 70 characters and spaces. The program will "line feed" automatically when the number of characters exceeds the available per line. A "line feed" may be forced by placing a blackslash at the location desired in the character string. The blackslash is not counted as a character. If the number of characters is greater than the block can hold, the system will respond with a CL WHAT?

After calculation of the character string, the system prints on the terminal a message indicating the block, and starting and ending channels of the string.

EXAMPLE:

Y 7074 U.C. MECHANICAL ENGINEERING BLOCK 0, CHANNELS 1 THROUGH 407

This information can be used to give a display at maximum display size as in the following keyboard program.

```
L 0
Y 3220 0 1 569 12
J 0
```

For an acceptable display for video taping, the storage scope must be used in the POINT DISPLAY mode.

10..1 INTERCHANGE - X

X N1 *** INTERCHANGE BUTTON ***

N1 = default - Modal Assurance Criteria

N1 = 1 Mode Scaling

N1 = 2 Mode Substraction

This section is interactive and relatively straight forward in nature. Remember a space terminates further entry.

10..2 LOAD - X<

X< N1 *** LOAD BUTTON ***

N1 = record where data is stored

10..3 STORE X>

X> N1 *** STORE BUTTON ***

N1 = record where data is to be stored.

FLOW CHART - DATA ACQUISITION

```
    **********
    * START  *
    **********
        +
        +
        +
        +
        +
***********************
* LOAD Y90 OVERLAY    *
***********************
* Y 90                *
***********************
* CL IREC1  IREC2     *
***********************
* K  0                *
***********************
* K  1                *
***********************
* K  2                *
***********************
* X>  IREC3           *
***********************
        +
        +
        +
        +
        +
        +
```

```
***********************
*                     *
* LOAD Y88 PROGRAM    *
*                     *
* (coreload 1)        *
*                     *
***********************
*                     *
* ENTER KEYBOARD      *
*                     *
* PROGRAM TO CALCULATE *
*                     *
* FREQUENCY RESPONSE  *
*                     *
* MEASUREMENTS IN     *
*                     *
* BLOCKS 1,2,3        *
*                     *
***********************
*                     *
* Y 88 N1 N2 N3 IREC3 *
*                     *
***********************
*                     *
* TAKE MEASUREMENTS   *
*                     *
* FOR EACH POINT OF   *
*                     *
* INTEREST            *
*                     *
***********************
```

FLOW CHART - MODE SHAPE ANALYSIS

```
     *************
     * START     *
     *************
          +
          +
          +
          +
          +
          +
**********************************
* LOAD LARGEST OVERLAY (10)      *
**********************************
* Y 9                            *
**********************************
* K 0  GENERAL SETUP             *
**********************************
* K 1  COMPONENT SETUP           *
**********************************
* K 2  GEOMETRY SETUP            *
**********************************
* K 3  CONNECTIVITY SETUP        *
**********************************
         +
         +
         +
         +         * * * *
         + + + +   *  A  *
         +         * * * *
         +
         +
         +
***********************************
*                                 *
*  A+   PARAMETER ESTIMATION      *
*       FREQUENCY                 *
*       DAMPING                   *
*       MODAL COEFFICIENTS        *
*                                 *
***********************************
        +
        +
        +        * * * *
        + + + +  *  A  *
        +        * * * *
        +
        +
        +
```

```
*******************************
*                             *
* D N1   DISPLAY MODES        *
*                             *
*******************************
        +
        +
        +
        +
     * * * *
     *     *
     *  B  *
     *     *
     * * * *
```

```
   * * * *
   *     *
   *  A  *
   *     *
   * * * *
      +
      +
      +
      +
      +
***********************************
*                                 *
*  X> N1   STORE PRESENT          *
*                                 *
*          INFORMATION TO         *
*                                 *
*          DISC                   *
*                                 *
***********************************
*                                 *
*  X< N1   READ PREVIOUSLY        *
*                                 *
*          ENTERED INFORMATION    *
*                                 *
*          FROM DISC              *
*                                 *
***********************************
```

```
                  * * * *
                  *     *
                  *  B  *
                  *     *
                  * * * *
                     +
                     +
                     +
                     +
                     +
         ************************************
         *                                  *
         *   B N1 N2  PLOT PRESENTLY        *
         *                                  *
         *            DISPLAYED MODE        *
         *                                  *
         *            SHAPE                 *
         *                                  *
         ************************************
         *                                  *
         * L  N1  N2  LABEL CURRENT         *
         *                                  *
         *            PLOT                  *
         *                                  *
         ************************************
         *                                  *
         * /L N1 N2   WRITE ASCII           *
         *                                  *
         *            TEXT TO               *
         *                                  *
         *            CRT SCREEN            *
         *                                  *
         ************************************
```

HEADER INFORMATION - MODAL DATA

WORD 6	52525B

ASCII STORAGE (SEARCH KEY)

WORD 9	70
WORD 10	TEST ID(1)
WORD 11	TEST ID(2)
WORD 12	TEST ID(3)
WORD 13	TEST ID(4)
WORD 14	TEST ID(5)
WORD 15	DELIMITER (.)
WORD 16	POINT NUMBER (1)
WORD 17	POINT NUMBER (2)
WORD 18	DELIMITER (.)
WORD 19	TRANSDUCER ORIENTATION
WORD 20	DELIMITER (.)
WORD 21	EXCITER LOCATION (1)
WORD 22	EXCITER LOCATION (2)
WORD 23	DELIMITER (.)
WORD 24	EXCITER ORIENTATION
WORD 25	DELIMITER (.)
WORD 26	DATE (1)
WORD 27	DATE (2)
WORD 28	DATE (3)
WORD 29	DELIMITER (.)
WORD 30	TIME (1)
WORD 31	TIME (2)
WORD 32	TIME (3)
WORD 33	DELIMITER (.)
WORD 34	DATA TYPE CODE
WORD 35	DELIMITER

INTEGER STORAGE

WORD 45	RESPONSE POINT NUMBER
WORD 46	EXCITATION POINT NUMBER
WORD 47	RESPONSE TRANSDUCER MODEL NUMBER
WORD 48	RESPONSE TRANSDUCER SERIAL NUMBER
WORD 49	LOAD CELL MODEL NUMBER
WORD 50	LOAD CELL SERIAL NUMBER
WORD 51	DATA BLOCK NUMBER

FLOATING POINT STORAGE

WORD 75	MINIMUM FREQUENCY
WORD 76	
WORD 77	DELTA FREQUENCY
WORD 78	
WORD 79	DATA CALIBRATION VALUE
WORD 80	OR - RECORD NUMBER

DATA TYPE CODES (WORD 34)

10	TIME
11	CORRELATION
20	FREQUENCY
21	FREQUENCY RESPONSE (D/F)
22	FREQUENCY RESPONSE (V/F)
23	FREQUENCY RESPONSE (A/F)
25	POWER SPECTRUM
29	COHERENCE
40	CURVE FIT DATA
59	
60	SYNTHESIZED DATA
70	SETUP
71	MODAL SETUP (Y 90)
72	MODAL COEFFICIENTS
75	TEST SETUP (Y 88)

6.2 Software Listing

```
FTN4,L
C
C                 VERSION    1-JUN-78  PM   MRH   COMMON: REV D
C
      SUBROUTINE Y0090(INT,IPAR)
      DIMENSION LINE(36),LINE1(35),IPAR(6),IH(1),IM(3),
     1 RH(3),NIH(5),CRH(3),ICMMD(14),IOID(2),IPT(2),
     2 IZR(10),IXX(1),IYY(1),IZZ(1),NX(3),NY(3),NZ(3),
     3 FN(10),FC(10),FM(10),FD(10)
      COMMON ICOMM,IT(5),ID(3),IX(3),IS(3),ID1,LMN,LSN,MN(3),
     1 ISN(3),IXP(3),IXDIR,ICF(5),IBW(5),IR(5),IAVG(5),IOVL(5),
     2 NAVG,NZR,NRS,KTEST,KTYPE,IREC,TCAL(3),IZOOM,FMIN,DF,KZ,KAVG
      EQUIVALENCE (LINE(2),LINE1)
      EXTERNAL  HDR8 , DTAD0 , SIZE
      DATA ICMMD/2H/R,2HCV,2HX ,2H$ ,2HCL,2HX(,2HX),2H/.,
     1 2H/L,2H( ,2HP ,2HR ,2HW ,2HK /
      DATA IDUM1/-1/,IZR/2HZ0,2HZ1,2HZ2,2HZ3,2HZ4,2HZ5,
     12HZ6,2HZ7,2HZ8,2HZ9/
C
C   *************************************************************
C                                                               *
C     THIS VERSION OF Y0090 HAS THE FOLLOWING FEATURES :        *
C                                                               *
C          1)  CORRECT HEADER INFORMATION                       *
C          2)  CORRECT TRANSDUCER INFO. IN HEADER               *
C          3)  INTERCHANGE TRANSDUCER INFO. FOR A POINT         *
C          4)  CHANGE OLD Y8 FORMAT TO CURRENT Y90 FORMAT       *
C          5)  CLEAR DISK RECORDS READY FOR Y88                 *
C          6)  LOAD OR STORE TEST SET-UP TO DISK                *
C          7)  SEARCH DISK RECORDS FOR A POINT NUMBER           *
C          8)  THREE TYPES OF RUN LOGS                          *
C          9)  PUNCH TEST SET-UP TO PAPER TAPE                  *
C         10)  READ TEST SET-UP FROM PAPER TAPE                 *
C         11)  ENTER TEST SET-UP FROM KEYBOARD                  *
C         12)  WRITE CURRENT TEST SET-UP                        *
C         13)  WRITE HEADER INFO. FROM DISK RECORD              *
C                                                               *
C   *************************************************************
C
      CALL SETAD(HDR8,IH,-8,0)
      CALL SETAD(HDR8,RH(1),67,0)
C
C
C      IPNTMX IS USED IN RUN LOG 2 .  IT IS USED TO SET
C      SYSTEM BLOC" SIZE SO IT MUST BE A POWER OF 2.
C
C
      IRECMX=819
      JRECMX=39
      IPNTMX=512
C
      CALL SETAD(DTAD0,IXX,IPNTMX,-1)
      I=IPNTMX*2
      CALL SETAD(DTAD0,IYY,I,-1)
      I=IPNTMX*3
      CALL SETAD(DTAD0,IZZ,I,-1)
```

```
      CALL GETI(SIZE,IBS)
      IBSIZE=IBS
      CALL IOSW(LU,0)
      WRITE(1,100)
  100 FORMAT(//," UCMIE  TEST SET-UP PROGRAM :  Y 90",/)
      IF(IDUM1.NE.-1) GOTO 200
      IPAR1= 1
      IPAR2= 0
      GO TO 8000
   50 IDUM1=0
  200 I=ISWR(140061B,0,0)
      WRITE(1,210)
  210 FORMAT(/,1H@ ,/)
      IPAR1=-9999
      IPAR2=-9999
      IPAR3=-9999
      IPAR4=-9999
      DO 230 I=1,36
  230 LINE(I) = 2H,,
      CALL TTYIN(LINE)
  242 CALL TEST(1,IST,LOG)
      IF(IST.LT.0) GOTO 242
      CALL CODE
      READ (LINE,320) IL
  320 FORMAT(A2)
      CALL CODE
      READ(LINE1,*) IPAR1,IPAR2,IPAR3,IPAR4
  330 IF(IL.EQ.2H**) GOTO 200
      NCMMD = 14
      DO 338 IMRH=1,NCMMD
      IF(IL.EQ.ICMMD(IMRH)) GOTO 344
  338 CONTINUE
      CALL IOSW(LU,0)
      WRITE(1,340)
  340 FORMAT(/,"INVALID COMMAND")
      GO TO 200
  344 IF(IMRH.GT.5) GOTO 350
      IF(IPAR1.EQ.-9999) GOTO 348
      IF(IPAR2.EQ.-9999) IPAR2=IPAR1
      GO TO 350
  348 IPAR1 = 1
      IPAR2 = IRECMX
  350 IF(IMRH.LT.8.OR.IMRH.GT.9) GOTO 360
      IF(IPAR2.EQ.-9999) GOTO 358
      IF(IPAR3.EQ.-9999) IPAR3=IPAR2
      GO TO 360
  358 IPAR2=1
      IPAR3=IRECMX
  360 GOTO(1000,9000,9500,2000,3000,4000,4500,4900,5000,
     1 9995,6400,6500,7000,8000) IMRH
C
C    ***************************************************************
C      CORRECT INFORMATION STORED IN HEADER AREA  ( /R )
C    ***************************************************************
C
 1000 CALL IOSW(LU,0)
```

```
      WRITE(1,1015)
 1015 FORMAT(/,"LIST HEADER WORDS ?",/,
     1 "(YES OR NO) :")
      READ(1,1017) IANS
 1017 FORMAT(A1)
      IF(IANS.EQ.1HY ) GOTO 1800
 1025 IF(ISSW(14).LT.0) GOTO 200
      WRITE(1,1030)
 1030 FORMAT(/,"ENTER HEADER WORD NUMBER:")
      READ(1,*) IK
      IF(ISSW(14).LT.0) GOTO 200
      IF(IK.EQ.6) GOTO 1601
      CALL HDRWD(IK,I)
      IF(I.EQ.1) GOTO 1035
      IF(I.EQ.0) GOTO 1043
      WRITE(1,1040) IK
 1040 FORMAT(/,"ERROR : TO CHANGE WORD NUMBER ",I3,/,
     1 "USE INTERCHANGE(X ) OR CONVOLUTION(CV) COMMANDS")
      GO TO 200
 1043 WRITE(1,1044) IK
 1044 FORMAT(/,I4," :  INVALID WORD NUMBER")
      GO TO 1025
 1035 WRITE(1,1041) IK
 1041 FORMAT(//,"ENTER NEW INFORMATION FOR",
     1 /,"WORD NUMBER :",I5)
C
C     READ NEW HEADER INFORMATION   *************************
C
      IF(IK.EQ.24) GOTO 1200
      IF(IK.EQ.34.OR.IK.EQ.36) GOTO 1250
      IF(IK.EQ.26) GOTO 1300
      IF(IK.GE.45.AND.IK.LT.75) GOTO 1400
      IF(IK.GE.75) GOTO 1500
      DO 1100 I=1,5
 1100 NIH(I)=2H
      READ(1,1101) (NIH(K),K=1,5)
 1101 FORMAT(5A2)
      GO TO 1601
 1200 READ(1,1210) NIH(1)
 1210 FORMAT(A2)
      IF(NIH(1).EQ.2H-X) NIH(1)=2HX-
      IF(NIH(1).EQ.2H-Y) NIH(1)=2HY-
      IF(NIH(1).EQ.2H-Z) NIH(1)=2HZ-
      GO TO 1601
 1250 READ(1,1210) NIH(1)
      GO TO 1601
 1300 READ(1,1301) NIH(1),NIH(2),NIH(3)
 1301 FORMAT(3A2)
      GO TO 1601
 1400 READ(1,*) NIH(1)
      GO TO 1601
 1500 I = (IK-73)/2
      READ(1,*) CRH(I)
 1601 IF(ISSW(14).LT.0) GOTO 200
      IF(IK.EQ.6) NIH(1)=52525B
      IF(IK.EQ.36) GOTO 1602
```

```
      IF(IK.EQ.75.OR.IK.EQ.77) GOTO 1602
      GO TO  1604
 1602 WRITE(1,1603)
 1603 FORMAT(/,"ENTER ZOOM RANGE TO BE SEARCHED FOR:")
      READ(1,1210) K
 1604 DO  1600  II=IPAR1,IPAR2
      CALL KYBD(2HMS,31,II)
      CALL KYBD(2HMS,11)
      IF(IH(6).EQ.12345.AND.IK.NE.6) GOTO 1600
      CALL BCHK(IBS,IH(5))
      IF(IK.EQ.6) GOTO 1700
      IF(IK.EQ.36) GOTO 1610
      IF(IK.EQ.75.OR.IK.EQ.77) GOTO 1610
      GO TO 1620
 1610 IF(IH(36).NE.K) GOTO 1600
C
C     STORE NEW INFORMATION IN HEADER   ********************
C
 1620 IF(IK.GT.50) GOTO 1710
 1700 IH(IK) = NIH(1)
      IF((IK.NE.10).AND.(IK.NE.26)) GOTO 1725
      IF(IK.EQ.10) NLPS=4
      IF(IK.EQ.26) NLPS=2
      J=IK
      DO 1705 N=1,NLPS
      L=N+1
      J=J+1
      IH(J) = NIH(L)
 1705 CONTINUE
      GO TO 1725
 1710 RH(I) = CRH(1)
 1725 IF(IK.NE.45.AND.IK.NE.46) GOTO 1730
      J=16
      DO 1726 N=45,46
      IPT(1)=IH(N)
      CALL ASCPT(IPT(1))
      IF(N.EQ.46) J=21
      IH(J)=IPT(1)
      IH(J+1)=IPT(2)
 1726 CONTINUE
C
C     STORE DATA WITH CORRECTED HEADER   ********************
C
 1730 CALL KYBD(2HMS,31,-1,1)
      CALL KYBD(2HMS,21)
 1600 CONTINUE
      GOTO 200
C
C     LIST HEADER WORD INFORMATION   ************************
C
 1800 CALL IOSW(NU,0)
      IF(NU.EQ.1) WRITE(NU,5028)
      WRITE(NU,1810)
 1810 FORMAT(/,10X," WORD #",10X,"USAGE",/)
      WRITE(NU,1819)
 1819 FORMAT(/,10X," ASCII STORAGE AREA",/)
```

```
      WRITE(NU,1811)
 1811 FORMAT(11X,"10",12X,"TEST ID")
      WRITE(NU,1812)
 1812 FORMAT(11X,"24",12X,"EXCITER ORIENTATION")
      WRITE(NU,1813)
 1813 FORMAT(11X,"26",12X,"DATE",/,11X,"30",12X,"TIME")
      WRITE(NU,1814)
 1814 FORMAT(11X,"34",12X,"DATA TYPE CODE",/,11X,"36",12X,"ZOOM RANGE")
      WRITE(NU,1817)
 1817 FORMAT(/,10X," INTEGER STORAGE AREA",/)
      WRITE(NU,1815)
 1815 FORMAT(11X,"45",12X,"RESPONSE POINT NUMBER",/,
     1 11X,"46",12X,"EXCITATION POINT NUMBER",/,
     2 11X,"49",12X,"LOAD CELL MODEL #",/,
     3 11X,"50",12X,"LOAD CELL SERIAL #")
      WRITE(NU,1818)
 1818 FORMAT(/,10X," REAL STORAGE AREA",/)
      WRITE(NU,1816)
 1816 FORMAT(11X,"75",12X,"MINIMUM FREQUENCY",/,
     1 11X,"77",12X,"DELTA FREQUENCY",/)
      GO TO 1025
C
C    ***************************************************
C     CHANGE OLD Y8 FORMAT TO NEW FORMAT USING HEADER AREA ( $   )
C    ***************************************************
C
 2000 CALL IOSW(LU,0)
      WRITE(1,2010)
 2010 FORMAT(/,"ENTER OLD TEST I.D. :")
      READ(1,2015) IOID(1),IOID(2)
 2015 FORMAT(2A2)
      WRITE(1,5004)
      READ(1,1210) IZOOM
      DO 2020 I=1,3
 2020 IM(I)=ID(I)
      DO 2040 IJ=IPAR1,IPAR2
      IF(ISSW(14).LT.0) GOTO 200
      CALL KYBD(2HMS,31,IJ)
      CALL KYBD(2HMS,11)
      CALL BCHK(IBS,IH(5))
C
C     GET OLD TEST ID
C
      II=IH(5)/2 - 20
      CALL GETW(0,II,IZ1,IZ3)
      II=II+1
      CALL GETW(0,II,IZ2,IZ3)
      IF((IZ1.NE.IOID(1)).OR.(IZ2.NE.IOID(2))) GOTO 2040
C
C     GET POINT , ORIENTATION AND DATE
C
      DO 2041 K=1,3
      II=II+1
      CALL GETW(0,II,IPT(1),0)
      CALL ASCPT(IPT(1))
      ID(K)=IPT(2)
```

```
 2041 CONTINUE
      II = II + 1
      CALL GETW(0,II,ID1,0)
      II = II + 1
      CALL GETW(0,II,IS(1),0)
      CALL KYBD(2HMS,31,-1,1)
      DO 2042 K=9,44
 2042 IH(K) = 2H .
      IF(ISSW(15).LT.0) GOTO 2043
      IF(ID1.EQ.2HX ) ID1 = 1
      IF(ID1.EQ.2H-X) ID1 = -1
      IF(ID1.EQ.2HY ) ID1 = 2
      IF(ID1.EQ.2H-Y) ID1 = -2
      IF(ID1.EQ.2HZ ) ID1 = 3
      IF(ID1.EQ.2H-Z) ID1 = -3
      CALL CODIT(IS(1),ID1)
      GO TO 2045
 2043 IF(ID1.EQ.2H-X) ID1=2HX-
      IF(ID1.EQ.2H-Y) ID1=2HY-
      IF(ID1.EQ.2H-Z) ID1=2HZ-
      IPT(1)=IS(1)
      CALL ASCPT(IPT(1))
      IS(2)=IPT(1)
      IS(3)=IPT(2)
C
C     PUT INFO INTO HEADER
C
 2045 CALL STORH(0)
      IH(36)=IZOOM
      IH(34)=2H23
      CALL KYBD(2HMS,21)
 2040 CONTINUE
      DO 2050 I=1,3
 2050 ID(I)=IM(I)
      GOTO 200
C
C    *******************************************************
C     CLEAR DATA RECORDS FOR USE BY Y88   ( CL )
C    *******************************************************
C
 3000 CALL IOSW(LU,0)
      DO 3040 II=IPAR1,IPAR2
      IF(ISSW(14).LT.0) GOTO 200
      CALL KYBD(2HMS,31,II)
      CALL KYBD(2HMS,11)
      CALL BCHK(IBS,IH(5))
      IH(6) = 12345
      CALL KYBD(2HMS,31,-1,1)
      CALL KYBD(2HMS,21)
 3040 CONTINUE
      GOTO 200
C
C    *********************************************************
C      READ TEST SET-UP   ( X( )
C    *********************************************************
C
```

```
 4000 IF(IPAR1.LT.0) IPAR1 = JRECMX
      CALL COM2(0,IPAR1)
C
C     CHECK HEADER FOR TYPE CODE OF "75"
C     IF NOT "75" , PRINT WARNING BUT PROCEED
C
      IF(IH(34).NE.2H75) WRITE(1,4002)
 4002 FORMAT(/,"NON-STANDARD SET-UP BLOCK")
      IPAR1 = 0
      NDIR=0
      DO 4010 I=1,3
      IF(MN(I).EQ.0) GOTO 4010
      NDIR=I
 4010 CONTINUE
      IFLAG2=0
      IF(LMN.NE.0) IFLAG2=1
      IF(NDIR.NE.0) IFLAG2=1
      IF(IXP(1).NE.0) IFLAG2=1
      IFLAG3=0
      IF(KTEST.NE.-1) IFLAG3=1
      KZOOM=1
      IF(NZR.EQ.0) GOTO 7000
      DO 4020 I=1,NZR
      IF(IR(I).NE.0.OR.IOVL(I).NE.0) KZOOM=0
 4020 CONTINUE
      GO TO 7000
C
C   ************************************************************
C       STORE TEST SET-UP    ( X) )
C   ************************************************************
C
 4500 IF(IPAR1.LT.0) IPAR1 = JRECMX
      CALL STORH(0)
      CALL COM2(1,IPAR1)
      GO TO 200
C
C  ************************************************************
C
C     SEARCH FOR POINT NUMBER    ( /. )
C
C  ************************************************************
C
 4900 CALL IOSW(LU,0)
      DO 4910 I=IPAR2,IPAR3
      IF(ISSW(14).LT.0) GOTO 200
      CALL KYBD(2HMS,31,I)
      CALL KYBD(2HMS,11)
      IF(IH(45).NE.IPAR1) GOTO 4910
      WRITE(LU,4905) IPAR1,IH(19),I
 4905 FORMAT(I4,1X,A2," IS IN RECORD ",I4)
 4910 CONTINUE
      GO TO 200
C
C   **********************************************************
C     PRINT RUN-LOG  ( /L )
C   **********************************************************
```

```
C
 5000 CALL IOSW(LU,0)
      IF(IPAR1.GT.4) GOTO 338
      IF(IPAR1.LE.0.OR.IPAR1.EQ.3) GOTO 5500
      WRITE(1,8120)
      READ(1,8125) (IT(II),II=1,5)
      IF(IPAR1.EQ.4) GOTO 5600
 5023 WRITE(1,5004)
 5004 FORMAT(/,"ENTER ZOOM RANGE :")
      READ(1,1210) IZOOM
C
C     ANALOG IN (RA) OR "ZA" WILL INDICATE ALL ZOOM RANGES
C
      IF(IZOOM.EQ.2HRA) IZOOM=2HZA
      IF(IPAR1.NE.2.AND.IZOOM.EQ.2HZA) GOTO 5025
      DO 5024 II=1,10
      IF(IZOOM.EQ.IZR(II)) GOTO 5025
 5024 CONTINUE
      WRITE(1,5008)
 5008 FORMAT(/,"INVALID RANGE")
      GO TO 5023
 5025 IF(IPAR1.EQ.2) GOTO 5100
C
C         RUN LOG  TYPE 1
C
C         GIVES RUN LOG BY RECORD NUMBER
C         FOR GIVEN TEST I.D.
C
      CALL IOSW(LU,0)
      NLIN=54
      IF(LU.NE.1) WRITE(LU,5080)
      IF(LU.NE.1) GO TO 5029
      NLIN=25
      WRITE(LU,5028)
 5028 FORMAT("")
 5029 WRITE(LU,5030)IT(1),IT(2),IT(3),IT(4),IT(5)
 5030 FORMAT(/,10X,"RUN LOG FOR TEST:  ",5A2)
      WRITE(LU,5035)IZOOM
 5035 FORMAT(/,10X,"ZOOM PARAMETER:      ",A2,//)
      WRITE(LU,5040)
 5040 FORMAT(59X,"FREQUENCY",/,10X,"RECORD",3X,"POINT",3X,
     $ "ORIENT",4X,"DATE",5X,"ZOOM",4X,"MINIMUM",4X,"MAXIMUM",/)
      III=0
      IFLAG=0
      DO 5090 IJ=IPAR2,IPAR3
      IF(ISSW(14).LT.0) GOTO 200
      CALL KYBD(2HMS,31,IJ)
      CALL KYBD(2HMS,11)
      CALL CHKID(IT,IC)
      IF(IC.EQ.0) GO TO 5090
      IF(ISSW(15).LT.0) GOTO 5090
C
C     CHECK DATA TYPE CODE FOR FREQ. DATA
C
      IC=IOR(IAND(IH(34),77400B),60B)
      IF(IC.EQ.2H70) GOTO 5062
```

```
          IF(IZOOM.EQ.2HZA) GO TO 5045
          IF(IH(36).NE.IZOOM) GO TO 5090
     5045 FM(1)=RH(1)+RH(2)*FLOAT(IH(5)/2)
          WRITE(LU,5060)IJ,IH(45),IH(19),IH(26),IH(27),IH(28),
         $ IH(36),RH(1),FM(1)
     5060 FORMAT(10X,I5,5X,I3,6X,A2,3X,3(1X,A2),4X,A2,1X,2F11.4)
          GO TO 5068
C
C         CHECK DATA TYPE CODE FOR TEST OR MODAL SET-UP
C
     5062 IC=IH(34)
          IF(IC.EQ.2H75) WRITE(LU,5063) IJ
          IF(IC.EQ.2H75) GOTO 5068
          IF(IC.NE.2H71) GOTO 5090
          IF(IJ.LE.(IFLAG+1)) GOTO 5090
          IFLAG=IJ
          WRITE(LU,5064) IJ
     5063 FORMAT(10X,I5,5X,".....  Y90: TEST SET-UP  .....")
     5064 FORMAT(10X,I5,5X,".....  Y 9: MODAL SET-UP  .....")
     5068 III=III+1
          IF(ISSW(0).LT.0) GOTO 5090
          IF(III.GE.NLIN)GO TO 5070
          GO TO 5090
     5070 IF(LU.EQ.1) GOTO 5081
          WRITE(LU,5080)
     5080 FORMAT(/////)
     5081 WRITE(LU,5030)IT(1),IT(2),IT(3),IT(4),IT(5)
          WRITE(LU,5035)IZOOM
          WRITE(LU,5040)
          IF(LU.EQ.1) NLIN=26
          III=0
     5090 CONTINUE
          GO TO 200
C
C            RUN LOG   TYPE 2
C
C            GIVES RUN LOG BY POINT NUMBER AND ORIENTATION
C            UNDER A GIVEN TEST I.D. AND ZOOM PARAMETER
C
     5100 IPTMAX=0
          IPTMIN=IPNTMX
          CALL KYBD(2HBS,IPNTMX)
          IBS=IPNTMX
          CALL KYBD(2HCL,1)
          CALL KYBD(2HCL,2)
          CALL KYBD(2HCL,3)
          DO 5200 I=IPAR2,IPAR3
          IF(ISSW(14).LT.0)GO TO 200
          CALL KYBD(2HMS,31,I)
          CALL KYBD(2HMS,11)
          CALL CHKID(IT,IC)
          IF(IC.EQ.0) GOTO 5200
          IF(IH(36).NE.IZOOM) GO TO 5200
C
C         CHECK DATA TYPE CODE FOR FREQ. DATA
C
```

```
      IC=IOR(60B,(IAND(IH(34),77400B)))
      IF(IC.EQ.2H70) GOTO 5200
C
      IS1=IH(45)
      IF(IS1.LE.0) GOTO 5200
      IF(IS1.GT.IPNTMX) GOTO 5200
      IF(IS1.GT.IPTMAX)IPTMAX=IS1
      IF(IS1.LT.IPTMIN)IPTMIN=IS1
      ID1=IH(19)
      IF(ID1.EQ.2HX ) IXX(IS1)= I
      IF(ID1.EQ.2HX-) IXX(IS1)=-I
      IF(ID1.EQ.2HY ) IYY(IS1)= I
      IF(ID1.EQ.2HY-) IYY(IS1)=-I
      IF(ID1.EQ.2HZ ) IZZ(IS1)= I
      IF(ID1.EQ.2HZ-) IZZ(IS1)=-I
 5200 CONTINUE
C
C     FIND LAST RECORD FOUND TO GET FREQ. INFO
C
      IF(IXX(IPTMAX).NE.0) I=IXX(IPTMAX)
      IF(IYY(IPTMAX).NE.0) I=IYY(IPTMAX)
      IF(IZZ(IPTMAX).NE.0) I=IZZ(IPTMAX)
      I=IABS(I)
      CALL KYBD(2HMS,31,I)
      CALL KYBD(2HMS,11)
      FM(1)=RH(1)+RH(2)*FLOAT(IH(5)/2)
      CALL IOSW(LU,0)
      NLIN=53
      IF(LU.NE.1) WRITE(LU,5080)
      IF(LU.NE.1) GOTO 5210
      NLIN=24
      WRITE(LU,5028)
 5210 WRITE(LU,5030)(IT(I),I=1,5)
      WRITE(LU,5215)IZOOM
 5215 FORMAT(/,10X,"ZOOM PARAMETER:      ",A2,/)
      WRITE(LU,5220) RH(1),FM(1)
 5220 FORMAT(10X,"MINIMUM FREQUENCY :",F15.7,/,10X,
     $ "MAXIMUM FREQUENCY :",F15.7,//)
      WRITE(LU,5270)
 5270 FORMAT(10X,"POINT NO.",5X,"X-DIR",8X,"Y-DIR"8X,"Z-DIR")
      III=0
      DO 5400 I=IPTMIN,IPTMAX
      IF(ISSW(14).LT.0) GO TO 200
C
C     IF NO DATA STORED FOR A POINT NUMBER HIGHER
C     THAN 250 , THEN SKIP PRINT OF THAT POINT.
C
      J=IXX(I)+IYY(I)+IZZ(I)
      IF(I.GT.250.AND.J.LE.0)GOTO 5400
      NX(1)=IXX(I)
      NY(1)=IYY(I)
      NZ(1)=IZZ(I)
      CALL ASCPT(NX(1))
      CALL ASCPT(NY(1))
      CALL ASCPT(NZ(1))
      IF(IXX(I).EQ.0) NX(1)=2H
```

```
      IF(IXX(I).EQ.0) NX(2)=2H-
      IF(IYY(I).EQ.0) NY(1)=2H
      IF(IYY(I).EQ.0) NY(2)=2H-
      IF(IZZ(I).EQ.0) NZ(1)=2H
      IF(IZZ(I).EQ.0) NZ(2)=2H-
      IF(ISSW(15).LT.0) GOTO 5400
      WRITE(LU,5350)I,NX(1),NX(2),NY(1),NY(2),NZ(1),NZ(2)
 5350 FORMAT(11X,I5,3(9X,2A2))
      III=III+1
      IF(ISSW(0).LT.0) GOTO 5400
      IF(III.GE.NLIN)GO TO 5360
      GO TO 5400
 5360 IF(LU.EQ.1) GOTO 5370
      WRITE(LU,5080)
 5370 WRITE(LU,5030)(IT(IJ),IJ=1,5)
      WRITE(LU,5215)IZOOM
      WRITE(LU,5220) RH(1),FM(1)
      WRITE(LU,5270)
      IF(LU.EQ.1) NLIN=25
      III=0
 5400 CONTINUE
      GO TO  200
C
C        RUN LOG   TYPE 3
C
C        GIVES SEQUENTIAL RUN LOG OF DISK
C
 5500 NLIN=59
      IF(LU.NE.1) WRITE(LU,5080)
      IF(LU.NE.1) GOTO 5501
      NLIN=30
      WRITE(LU,5028)
 5501 WRITE(LU,5502)
 5502 FORMAT(/,10X,"RECORD",3X,"TEST ID",5X,"ZOOM",3X,"TYPE",
     $ 3X,"POINT",2X,"ORIENT",4X,"DATE",//)
      III=0
      IFLAG=0
      DO 5510 I=IPAR2,IPAR3
      IF(ISSW(14).LT.0) GOTO 200
      CALL KYBD(2HMS,31,I)
      CALL KYBD(2HMS,11)
      IF(IH(6).NE.52525B)GO TO 5510
      IF(ISSW(15).LT.0) GOTO 5510
      IC=IOR(IAND(IH(34),77400B),60B)
      IF(IC.EQ.2H70) GOTO 5520
      WRITE(LU,5505)I,IH(10),IH(11),IH(12),IH(13),IH(14),IH(36),
     1 IH(34),IH(45),IH(19),IH(26),IH(27),IH(28)
 5505 FORMAT(11X,I4,4X,5A2,3X,A2,5X,A2,I8,6X,A2,3X,3(A2,1X))
      GO TO 5515
 5520 IC=IH(34)
      IF(IC.EQ.2H75) WRITE(LU,5522) I,(IH(J),J=10,14)
      IF(IC.EQ.2H75) GOTO 5515
      IF(IC.NE.2H71) GOTO 5510
      IF(I.LE.IFLAG+1) GOTO 5510
      IFLAG=I
      WRITE(LU,5524) I,(IH(J),J=10,14)
```

```
 5522 FORMAT('   ,I4,4X,5A2,3X,".....  Y90: TEST SET-UP  .....")
 5524 FORMAT(1X,I4,4X,5A2,3X,".....  Y 9: MODAL SET-UP  .....")
 5515 III=III+1
      IF(ISSW(0).LT.0) GOTO 5510
      IF(III.GE.NLIN)GO TO 5507
      GO TO 5510
 5507 IF(LU.EQ.1) GOTO 5508
      WRITE(LU,5080)
 5508 WRITE(LU,5502)
      IF(LU.EQ.1) NLIN=31
      III=0
 5510 CONTINUE
      GO TO 200
C
C                       "RUN-LOG" TYPE 4
C
C     LIST FMIN , FCNTR , FMAX , FDELT FOR ZOOM RANGES
C     UNDER GIVEN TEST I.D. BETWEEN RECORDS IPAR2 & IPAR3
C
 5600 IF(LU.EQ.1) WRITE(LU,5028)
      WRITE(LU,5602) (IT(I),I=1,5)
 5602 FORMAT(/,10X,"TEST I.D. : ",5A2)
      WRITE(LU,5604)
 5604 FORMAT(/,7X,"ZOOM",27X,"FREQUENCIES",/,6X,"RANGE",6X,
     $ "MINIMUM",9X,"CENTER",8X,"MAXIMUM",10X,"DELTA",/)
      DO 5606 I=1,6
      FN(I)=0.
      FC(I)=0.
      FM(I)=0.
      FD(I)=0.
 5606 CONTINUE
      DO 5620 I=IPAR2,IPAR3
      IF(ISSW(14).LT.0) GOTO 200
      CALL KYBD(2HMS,31,I)
      CALL KYBD(2HMS,11)
      CALL CHKID(IT,IC)
      IF(IC.EQ.0) GOTO 5620
      IC=IOR(IAND(IH(34),77400B),60B)
      IF(IC.EQ.2H70) GOTO 5620
      III=0
      DO 5608 II=1,10
      IF(IZR(II).NE.IH(36)) GOTO 5608
      III=II
 5608 CONTINUE
      IF(III.EQ.0) GOTO 5620
      IF(FC(III).EQ.0) GOTO 5610
      FTEST=RH(1)+RH(2)*FLOAT(IH(5)/2)
      FTEST=ABS(1.0 - FTEST/FM(III))
C
C   ********  FTEST & FM WITHIN 1%  ?      *********
C
      IF(FTEST.LT.0.001) GOTO 5620
      IF(ISSW(15).LT.0) GOTO 5620
      WRITE(LU,5611) IH(36),I
 5611 FORMAT("    DISCREPENCY IN FREQUENCIES FOUND FOR",
     $ 1X,"ZOOM RANGE ",A2," AT RECORD",I4)
```

```
      GO TO 5620
 5610 FN(III)=RH(1)
      FD(III)=RH(2)
      FTEST=RH(2)*FLOAT(IH(5)/4)
      FC(III)=RH(1)+FTEST
      FM(III)=FC(III)+FTEST
 5620 CONTINUE
      DO 5630 I=1,10
      IF(FC(I).EQ.0) GOTO 5630
      WRITE(LU,5635) IZR(I),FN(I),FC(I),FM(I),FD(I)
 5635 FORMAT(8X,A2,4F15.7)
 5630 CONTINUE
      GO TO 200
C
C   **************************************************************
C     PUNCH TEST SET-UP
C   **************************************************************
C
 6400 LU=4
C
C      PUNCHED PAPER TAPE MUST BEGIN WITH AN ASTERISK
C
      WRITE(LU,6401)
 6401 FORMAT("*")
C
      WRITE(LU,8125) (IT(I),I=1,5)
      WRITE(LU,8135) (ID(I),I=1,3)
      WRITE(LU,6403) IREC,IXP(1),KTYPE,IXP(2),IXP(3),IXDIR,
     $ LMN,LSN,NDIR,IFLAG2,IFLAG3
 6403 FORMAT(2I4,4A2,2I10,3I2)
      DO 6404 I=1,3
 6404 WRITE(LU,6405) I,MN(I),ISN(I),TCAL(I)
 6405 FORMAT(I3,2I10,E15.7)
      WRITE(LU,6406) KZOOM,KTEST,NZR
 6406 FORMAT(3I2)
      DO 6407 I=1,5
 6407 WRITE(LU,7441) ICF(I),IBW(I),IR(I),IAVG(I),IOVL(I)
      GO TO 200
C
C   **************************************************************
C     PHOTOREAD OPTION FOR INPUTTING TEST SET-UP
C   **************************************************************
C
 6500 PAUSE 1
      LU=5
C
C      SEARCH LEADER FOR AN ASTERISK
C
      CALL POSIT(5)
C
      READ(LU,8125) (IT(I),I=1,5)
      READ(LU,8135) (ID(I),I=1,3)
      READ(LU,6403) IREC,IXP(1),KTYPE,IXP(2),IXP(3),IXDIR,
     $ LMN,LSN,NDIR,IFLAG2,IFLAG3
      DO 6503 I=1,3
 6503 READ(LU,6405) I,MN(I),ISN(I),TCAL(I)
```

```
      READ(LU,6406) KZOOM,KTEST,NZR
      DO 6505 I=1,5
 6505 READ(LU,7441) ICF(I),IBW(I),IR(I),IAVG(I),IOVL(I)
      I=ISWR(40B,0,0)
      IPAR1=0
      GOTO 7000
C
C     **********************************************************
C       WRITE TEST SET-UP INFORMATION   ( W )
C     **********************************************************
C
 7000 CALL IOSW(LU,0)
      IF(LU.EQ.4) GOTO 6400
      IF(IPAR1.GT.3) IPAR1=0
      IF(LU.EQ.1.AND.IPAR1.LT.0) WRITE(LU,5028)
      IF(IPAR1.EQ.1) GOTO 7300
      IF(IPAR1.EQ.2) GOTO 7400
      IF(IPAR1.EQ.3) GOTO 7500
C
C     WRITE TEST ID & DATE   *************************
C
      WRITE(LU,7201) (IT(II),II=1,5)
 7201 FORMAT(///,10X," TEST ID :   ",5A2)
      WRITE(LU,7202) (ID(II),II=1,3)
 7202 FORMAT(/,10X," DATE :  ",3(A2,1X))
      WRITE(LU,7203) IREC
 7203 FORMAT(/,10X," DATA START RECORD : ",I5)
      IF(IPAR1.EQ.0) GOTO 200
      IF(ISSW(14).LT.0) GOTO 200
C
C     WRITE EXCITER AND TRANSDUCER INFORMATION  ******
C
 7300 IF(IFLAG2.NE.0) GOTO 7310
      WRITE(LU,7309)
 7309 FORMAT(/,10X," NO LOAD CELL OR TRANSDUCER INFORMATION")
      IF(IPAR1.EQ.2) GOTO 200
      GO TO 7400
 7310 WRITE(LU,7301) IXP(1),IXDIR
 7301 FORMAT(///,10X," EXCITER POSITION :  ",I4,/,10X,
     1 " EXCITER ORIENTATION :  ",A2)
      WRITE(LU,7302) LMN,LSN
 7302 FORMAT(/,10X," LOAD CELL MODEL #  ",I11,/,10X,
     1 " LOAD CELL SERIAL #  ",I10)
      IF(NDIR.EQ.0) GOTO 7306
      WRITE(LU,7303)
 7303 FORMAT(///,10X," RESPONSE TRANSDUCER(S)",//,11X,"NUMBER",
     1 9X,"MODEL #",10X,"SERIAL #",6X,"CALIBRATION",/)
      DO 7304 II=1,NDIR
      WRITE(LU,7305) II,MN(II),ISN(II),TCAL(II)
 7305 FORMAT(10X,I4,7X,I10,8X,I10,5X,F12.3)
 7304 CONTINUE
 7306 IF(IPAR1.EQ.1) GOTO 200
      IF(ISSW(14).LT.0) GOTO 200
C
C     WRITE  ZOOM INFORMATION   **********************
C
```

```
 7400 IF(IFLAG3.NE.0) GOTO 7401
      WRITE(LU,7405)
 7405 FORMAT(/,10X," NO ZOOM TEST INFORMATION")
      GO TO 200
 7401 WRITE(LU,7408) KTYPE
 7408 FORMAT(//,10X," DATA TYPE CODE:",2X,A2)
      IF(KTEST.EQ.0) WRITE(LU,7411)
      IF(KTEST.EQ.1) WRITE(LU,7421)
 7411 FORMAT(/,10X," TEST TYPE :   IMPACT")
 7421 FORMAT(/,10X," TEST TYPE :   RANDOM")
      IF(NZR.EQ.0) GOTO 200
      IF(KZOOM.EQ.0) WRITE(LU,7431)
      IF(KZOOM.EQ.1) WRITE(LU,7432)
 7431 FORMAT(/,10X," CNTRFRQ",3X,"BNDWDTH",4X,"BGNREC",3X,
     $ "NUMAVGS",3X,"OVLPFAC")
 7432 FORMAT(/,10X," CENTER FREQ",6X,"BANDWIDTH",5X,"NO. AVERAGES")
      DO 7440 II=1,NZR
      IF(KZOOM.EQ.1) GOTO 7443
      WRITE(LU,7441) ICF(II),IBW(II),IR(II),IAVG(II),IOVL(II)
      GO TO 7440
 7443 WRITE(LU,7442) ICF(II),IBW(II),IAVG(II)
 7441 FORMAT(6X,5I10)
 7442 FORMAT(4X,3I15)
 7440 CONTINUE
      GO TO 200
C
C     WRITE HEADER INFO STORED WITH DATA RECORD IPAR2
C
 7500 IF(IPAR2.LT.0.OR.IPAR2.GT.IRECMX) GOTO 338
      CALL KYBD(2HMS,31,IPAR2)
      CALL KYBD(2HMS,11)
      IF(IH(6).EQ.12345) GOTO 7598
      IF(IPAR3.GE.0) GOTO 7600
      IF(LU.EQ.1) WRITE(LU,5028)
      WRITE(LU,7502) IPAR2
 7502 FORMAT(10X,"HEADER INFORMATION FOR RECORD",I5,/)
      WRITE(LU,7504) (IH(I),I=10,14)
 7504 FORMAT(/,10X,"TEST I.D..................",5A2)
      WRITE(LU,7506) (IH(I),I=26,28)
 7506 FORMAT(10X,"DATE......................",3A2,/)
      WRITE(LU,7508) IH(16),IH(17)
 7508 FORMAT(10X,"POINT NUMBER..............",2A2)
      WRITE(LU,7510) IH(19)
 7510 FORMAT(10X,"TRANSDUCER ORIENTATION....",2X,A2,/)
      WRITE(LU,7516) IH(36),IH(34)
 7516 FORMAT(10X,"ZOOM RANGE................",2X,A2,/,
     1 10X,"DATA TYPE.................",2X,A2)
      WRITE(LU,7511) IH(51)
 7511 FORMAT(10X,"TRANSDUCER NUMBER.........",I3,/)
      WRITE(LU,7512) IH(21),IH(22)
 7512 FORMAT(10X,"EXCITER LOCATION..........",2A2)
      WRITE(LU,7514) IH(24)
 7514 FORMAT(10X,"EXCITER ORIENTATION.......",2X,A2,/)
      WRITE(LU,7518) (IH(I),I=47,50)
 7518 FORMAT(10X,"TRANSDUCER MODEL NUMBER...",I6,/,
     1 10X,"TRANSDUCER SERIAL NUMBER..",I6,//,
```

```
     2 10X,"LOAD CELL MODEL NUMBER....",I6,/,
     3 10X,"LOAD CELL SERIAL NUMBER...",I6,/)
      WRITE(LU,7520) (RH(I),I=1,3)
 7520 FORMAT(10X,"MINIMUM FREQUENCY.........",F15.7,/,
     2 10X,"DELTA FREQUENCY...........",F15.7,//,
     3 10X,"DATA CALIBRATION NUMBER...",F15.7,/)
      GO TO 200
 7598 WRITE(LU,7599) IPAR2
 7599 FORMAT(/,"RECORD",I4," IS CLEARED")
      GO TO 200
C
C     WRITE HEADER WORD NUMBER IPAR3 FOR RECORD IPAR2
C
 7600 WRITE(LU,7502) IPAR2
      WRITE(LU,7610) IPAR3
 7610 FORMAT(10X,"WORD",I4," CONTAINS :",/)
      IF(IPAR3.LT.10) WRITE(LU,7615) IH(IPAR3)
      IF(IPAR3.GE.10.AND.IPAR3.LT.45) WRITE(LU,7620) IH(IPAR3)
      IF(IPAR3.GE.45.AND.IPAR3.LT.75) WRITE(LU,7630) IH(IPAR3)
      IF(IPAR3.LT.75) GOTO 200
      IPAR3=(IPAR3-73)/2
      WRITE(LU,7640) RH(IPAR3)
 7615 FORMAT(10X,@7,"B")
 7620 FORMAT(10X,A2)
 7630 FORMAT(10X,I10)
 7640 FORMAT(10X,E15.7)
      GOTO 200
C
C   ***********************************************************
C     ENTER TEST SET-UP THRU KEYBOARD   ( K )
C    **********************************************************
C
 8000 CALL IOSW(LU,1)
      IF(LU.EQ.5) GOTO 6500
      IF(IPAR1.LE.0) IPAR1=0
      IF(IPAR1.EQ.0) GOTO 8100
      IF(IPAR1.EQ.1) GOTO 8200
      IF(IPAR1.EQ.2) GOTO 8300
      GO TO 338
C
C     KEYBOARD  0  ***********    TEST ID & DATE  ************
C
 8100 DO 8111 II = 1,5
 8111 IT(II) = 2H
      WRITE(1,8120)
 8120 FORMAT(/,"ENTER TEST I.D. :")
      READ(1,8125) (IT(II),II=1,5)
 8125 FORMAT(5A2)
      WRITE(1,8130)
 8130 FORMAT(/,"ENTER DATE :")
      READ(1,8135) ID(1),ID(2),ID(3)
 8135 FORMAT(3A2)
      WRITE(1,8140)
 8140 FORMAT(/,"ENTER DISK STORAGE START RECORD :")
      READ(1,*) IREC
      IF(IREC.LE.0.OR.IREC.GT.IRECMX) IREC=1
```

```
      GO TO 200
C
C     KEYBOARD  1  ***********   LOAD CELL & TRANSDUCER  *****
C
C                                K 1 0 : INITIALIZES SET-UP
C
 8200 IF(IPAR2.NE.0) GOTO 8205
      IFLAG2=0
      IS(1)=0
      NDIR=1
      LMN=0
      LSN=0
      IXDIR=2H
      DO 8202 II=1,3
      IX(II)=II
      MN(II)=0
      ISN(II)=0
      TCAL(II)=1.0
      IXP(II)=2H
 8202 CONTINUE
      IXP(1)=0
      IF(IDUM1.EQ.-1) GOTO 8300
      GO TO 200
 8205 IFLAG2=1
      WRITE(1,8210)
 8210 FORMAT(/,"ENTER EXCITER POSITION AND DIRECTION: [ INTEGERS ]")
      READ(1,*) IXP(1),IXDIR
      CALL CODIT(IXP(1),IXDIR)
      WRITE(1,8220)
 8220 FORMAT(/,"ENTER LOAD CELL  MODEL #  AND  SERIAL # :")
      READ(1,*) LMN,LSN
      WRITE(1,8230)
 8230 FORMAT(/,"ENTER NUMBER OF RESPONSE DIRECTIONS :")
      READ(1,*) NDIR
      IF(NDIR.EQ.0) GOTO 200
      WRITE(1,8240) NDIR
 8240 FORMAT(/,"ENTER",I3,"  RESPONSE TRANSDUCER'S",/,
     1 " MODEL NUMBER , SERIAL NUMBER , CALIBRATION NUMBER :")
      DO 8245 II=1,NDIR
 8245 READ(1,*) MN(II),ISN(II),TCAL(II)
      GO TO 200
C
C     KEYBOARD  2  ***********   ZOOM  INFORMATION  **********
C
C                                K 2 0 : INITIALIZES SET-UP
C
 8300 IF(IPAR2.NE.0) GOTO 8305
      IFLAG3=0
      NZR=0
      KZOOM=1
      KTEST=-1
      KTYPE=2H20
      DO 8302 II=1,5
      ICF(II)=0
      IBW(II)=0
      IR(II) =0
```

```
            IAVG(II)=0
            IOVL(II)=0
       8302 CONTINUE
            IF(IDUM1.EQ.-1) GOTO 50
            GO TO 200
       8305 IFLAG3=1
            WRITE(1,8306)
       8306 FORMAT(/,"ENTER DATA TYPE CODE (2 CHARACTER):")
            READ(1,8307) KTYPE
       8307 FORMAT(A2)
            WRITE(1,8330)
       8330 FORMAT(/,"ENTER ZERO FOR IMPACT OR ONE FOR RANDOM :")
            READ(1,*) KTEST
       8301 WRITE(1,8310)
       8310 FORMAT(/,"INPUT NUMBER OF ZOOM RANGES :")
            READ(1,*) NZR
            IF(NZR.LE.0) GOTO 200
            IF(NZR.GT.5) GOTO 8301
            WRITE(1,8315)
       8315 FORMAT(/,"ENTER  1  FOR ON-LINE ZOOM OR",/,
          $ 7X,"0  FOR OFF-LINE ZOOM :")
            READ(1,*) KZOOM
            IF(KZOOM.EQ.1) WRITE(1,8319)
            IF(KZOOM.EQ.0) WRITE(1,8320)
       8319 FORMAT(//,"FOR EACH ZOOM RANGE INPUT :",/,"CENTER FREQUENCY ,",
          $ 1X,"BANDWIDTH , NUMBER OF AVERAGES")
       8320 FORMAT(//,"FOR EACH ZOOM RANGE INPUT :",/," CNTR FREQ , BNDWDTH",
          1 " , BEGNG REC , NO. AVGS , OVRLP FAC")
            DO 8325 II=1,NZR
            IF(KZOOM.EQ.1) GOTO 8322
            IF(KZOOM.EQ.0) GOTO 8324
       8322 READ(1,*) ICF(II),IBW(II),IAVG(II)
            GO TO 8325
       8324 READ(1,*) ICF(II),IBW(II),IR(II),IAVG(II),IOVL(II)
       8325 CONTINUE
            GO TO 200
      C
      C   ***********************************************************
      C
      C     REPLACE DATA ASSOCIATED WITH A PARTICULAR TRANSDUCER
      C             SUCH AS MODEL# , SERIAL# OR CALIBRATION#      ( CV )
      C
      C   ***********************************************************
      C
       9000 WRITE(1,1015)
            READ(1,1017) IANS
            IF(IANS.EQ.1HY ) GOTO 9400
       9001 IF(ISSW(14).LT.0) GOTO 200
       9009 ISER=0
            WRITE(1,9007)
       9007 FORMAT(/,"ENTER TRANSDUCER NUMBER",/,
          $ "OF DATA TO BE CORRECTED :")
      C
      C     VALID NUMBERS ARE 0,1,2,3
      C
            READ(1,*) N
```

```
      IF(ISSW(14).LT.0) GOTO 200
      IF(N.GE.0.AND.N.LE.3) GOTO 9002
C
C     IF TRANSDUCER NUMBER IS NOT VALID THEN USE
C     SERIAL NUMBER FOR SEARCH.
C
      ISER=1
      WRITE(1,9008)
 9008 FORMAT(/,"ENTER SERIAL NUMBER INSTEAD:")
      READ(1,*) N
      IF(ISSW(14).LT.0) GOTO 200
      IF(N.GT.0) GOTO 9002
      WRITE(1,9010) N
 9010 FORMAT(/,I15," :  INVALID NUMBER")
      GO TO 9009
 9002 WRITE(1,1030)
      READ(1,*) IK
      IF(ISSW(14).LT.0) GOTO 200
      CALL HDRWD(IK,I)
      IF(I.NE.0) GOTO 9003
      WRITE(1,1044) IK
      GO TO 9002
 9003 IF(I.NE.1) GOTO 9005
      WRITE(1,9004) IK
 9004 FORMAT(/,"TO CHANGE WORD NUMBER",I3," USE THE",/,
     $ "REPLACE COMMAND (/R)")
      GO TO 200
 9005 WRITE(1,1041) IK
      IF(ISSW(14).LT.0) GOTO 200
      IF(IK.GE.75) READ(1,*) CRH(1)
      IF(IK.GE.45.AND.IK.LT.75) READ(1,*) NIH(1)
      IF(IK.NE.19) GOTO 9020
      READ(1,1210) NIH(1)
      IF(NIH(1).EQ.2H-X) NIH(1)=2HX-
      IF(NIH(1).EQ.2H-Y) NIH(1)=2HY-
      IF(NIH(1).EQ.2H-Z) NIH(1)=2HZ-
 9020 DO 9100 I=IPAR1,IPAR2
      IF(ISSW(14).LT.0) GOTO 9200
      CALL KYBD(2HMS,31,I)
      CALL KYBD(2HMS,11)
      IF(IH(6).NE.52525B) GOTO 9100
      CALL BCHK(IBS,IH(5))
C
C     IF TRANSDUCER NUMBER IS ZERO THEN REPLACE WITHOUT CHECK
C
      IF(N.EQ.0) GOTO 9025
      IF(ISER.EQ.0.AND.IH(51).NE.N) GOTO 9100
      IF(ISER.EQ.1.AND.IH(48).NE.N) GOTO 9100
 9025 IF(IK.GE.75) GOTO 9030
      IH(IK)=NIH(1)
      GO TO 9040
 9030 IJ=(IK-73)/2
      RH(IJ)=CRH(1)
 9040 CALL KYBD(2HMS,31,-1,1)
      CALL KYBD(2HMS,21)
 9100 CONTINUE
```

```
      GO TO 200
C
C     EXIT BEFORE COMPLETING ALL RECORDS
C
 9200 IF(I.EQ.IPAR1) GOTO 200
      IJ=I-1
      WRITE(1,9210) IJ,I
 9210 FORMAT(/,"RECORDS THROUGH",I4," HAVE BEEN SEARCHED",/,
     $ "RECORDS FROM",I4," ON HAVE NOT BEEN ALTERED")
      GO TO 200
C
C     LIST HEADER WORD INFORMATION
C
 9400 I=9001
      GO TO 9410
 9401 I=9501
 9410 CALL IOSW(NU,0)
      IF(NU.EQ.1) WRITE(NU,5028)
      WRITE(NU,1810)
      WRITE(NU,1819)
      WRITE(NU,9420)
 9420 FORMAT(12X,"19",11X,"TRANSDUCER ORIENTATION")
      WRITE(NU,1817)
      WRITE(NU,9430)
 9430 FORMAT(12X,"47",11X,"RESPONSE TRANSDUCER MODEL #",/,
     1 12X,"48",11X,"RESPONSE TRANSDUCER SERIAL #",/,
     2 12X,"51",11X,"RESPONSE TRANSDUCER NUMBER")
      WRITE(NU,1818)
      WRITE(NU,9440)
 9440 FORMAT(12X,"79",11X,"DATA CALIBRATION OR RECORD #",/)
      IF(I.EQ.9501) GOTO 9501
      GOTO 9001
C
C  ****************************************************************
C
C      INTERCHANGE TRANSDUCER INFORMATION    ( X   )
C
C  ****************************************************************
C
 9500 WRITE(1,3030)IPAR1,IPAR2
 3030 FORMAT(/,"YOU ARE ABOUT TO ALTER RECORDS",I5,"  THROUGH",
     1 I5,/,"IS THIS CORRECT ?  (YES OR NO)")
      READ(1,1017) IANS
      IF(IANS.NE.1HY ) GOTO 200
      WRITE(1,1015)
      READ(1,1017) IANS
      IF(IANS.EQ.2HY ) GOTO 9401
 9501 WRITE(1,8120)
      READ(1,8125) (IT(I),I=1,5)
      IF(ISSW(14).LT.0) GOTO 200
 9505 WRITE(1,8230)
      READ(1,*) ND
      IF(ND.LT.1.OR.ND.GT.3) GOTO 9505
      WRITE(1,9506)
 9506 FORMAT(/,"ENTER NEW AND CORRESPONDING OLD TRANSDUCER NUMBERS")
C
```

```
C      THIS TABLE WILL INDICATE WHICH DATA WILL BE STORED WHERE
C      IE: THE RECORD WITH THE FIRST NUMBER (NEW) WILL RECEIVE
C      THE DATA NOW STORED IN THE RECORD WITH THE SECOND (OLD)
C      NUMBER.
C
       DO 9508 I=1,ND
 9508 READ(1,*) NX(I),NY(I)
 9518 DO 9513 I=1,5
 9513 IYY(I)=-9999
       WRITE(1,9514)
 9514 FORMAT(/,"ENTER HEADER WORD NUMBERS",1X,
     1 "TO BE INTERCHANGED",/,"(19,47,48 AND/OR 79) ",3X,
     2 "(TERMINATE LIST WITH A ZERO)")
C
C  THE ABOVE STATEMENT DOES NOT INCLUDE WORD 51 , HOWEVER THE
C  PROGRAM ALLOWS IT TO BE INTERCHANGED ALSO.
C  IT IS NOT INCLUDED BECAUSE THE USER MAY SIMPLY COPY THE
C  NUMBERS AND 51 IS ONE THAT SHOULD NOT BE CHANGED INDISCRIMANTLY
C
       DO 9515 I=1,5
       READ(1,*) IK
       IF(IK.LE.0) GOTO 9510
       CALL HDRWD(IK,J)
       IF(ISSW(14).LT.0) GOTO 200
       IF(J.EQ.2) GOTO 9517
       WRITE(1,1044) IK
       GO TO 9518
 9517 IYY(I)=IK
 9515 CONTINUE
 9510 WRITE(1,9507)
 9507 FORMAT(/,"ENTER POINT NUMBERS WHERE TRANSDUCER ",1X,
     1 "INFORMATION",/,"IS TO BE INTERCHANGED (TERMINATE LIST",1X,
     2 "WITH A ZERO)")
       I=0
 9509 J=-9999
       K=-9999
       READ(1,*) J,K
       IF(K.GT.0) GOTO 9511
       IF(J.LE.0) GOTO 9520
       I=I+1
       IXX(I)=J
       GOTO 9509
 9511 M=1
       IF(J.GT.K) M=-1
 9512 I=I+1
       IXX(I)=J
       IF(J.EQ.K) GOTO 9509
       J=J+M
       GO TO 9512
 9520 IF(I.LE.0) GOTO 200
       WRITE(1,9525)
 9525 FORMAT(/,"LIST POINT NUMBERS ?  (YES OR NO)")
       READ(1,1017) IANS
       IF(IANS.NE.1HY ) GOTO 9528
       CALL IOSW(LU,0)
       WRITE(LU,9526)
```

```
 9526 FORMAT(/,"POINT NUMBERS",/)
      DO 9529 J=1,I
      WRITE(LU,9527) IXX(J)
 9527 FORMAT(I5)
 9529 CONTINUE
      WRITE(1,9521)
 9521 FORMAT(/,"ARE POINTS CORRECT? (YES OR NO)")
      READ(1,1017) IANS
      IF(IANS.NE.1HY ) GOTO 9510
C
C     NO EDIT OF POINT NUMBERS ALLOWED
C
 9528 M=IPAR1
      DO 9590 KJ=1,I
 9530 NP=0
C
C     FOR EACH POINT SEARCH FOR A NUMBER OF RECORDS
C     EQUAL TO THE NUMBER OF DIRECTIONS.
C
      DO 9550 J=M,IPAR2
      IF(ISSW(14).LT.0) GOTO 9600
      CALL KYBD(2HMS,31,J)
      CALL KYBD(2HMS,11)
      CALL CHKID(IT,IC)
      IF(IC.EQ.0) GOTO 9550
      IF(IH(45).NE.IXX(KJ)) GOTO 9550
      NP=NP+1
C
C     TEST FOR TOO MANY RECORDS FOUND FOR THIS POINT
C
      IF(NP.GT.ND) GOTO 9552
      IM(NP)=J
      IF(NP.EQ.1) GOTO 9540
      NP1=NP-1
C
C     TEST TO SEE IF THIS DIRECTION HAS ALREADY BEEN FOUND
C
      DO 9535 MJ=1,NP1
      IF(IM(MJ).NE.J) GOTO 9535
      NP=NP1
      GO TO 9557
 9535 CONTINUE
C
C     TEST TO SEE IF ALL DIRECTIONS HAVE BEEN FOUND
C
 9540 IF(NP.LT.ND) GOTO 9550
      GO TO 9560
 9550 CONTINUE
      IF(NP.LT.ND.AND.M.EQ.IPAR1) GOTO 9557
      M=IPAR1
      GO TO 9530
 9552 WRITE(1,9553) IXX(KJ)
 9553 FORMAT(/,"POINT NUMBER",I4," HAS MORE DIRECTIONS THAN",1X,
     $ "SPECIFIED",/,"THIS POINT WILL BE SKIPPED")
      GO TO 9590
 9557 WRITE(1,9558) IXX(KJ),NP,ND
```

```
 9558 FORMAT(/,"POINT NUMBER",I4,/,
     1 "ONLY",I3," OF THE",I3," DIRECTIONS FOUND",/,
     2 "THIS POINT WILL BE SKIPPED")
      GO TO 9590
 9560 M=J
      DO 9561 J=1,ND
 9561 NZ(J)=IM(J)
      DO 9562 J=1,ND
      CALL KYBD(2HMS,31,NZ(J))
      CALL KYBD(2HMS,11)
      K=IH(51)
      DO 9563 KK=1,ND
      IF(NX(KK).EQ.K) GOTO 9564
 9563 CONTINUE
      WRITE(1,9567) IXX(KJ)
 9567 FORMAT(/,"ERROR IN TRANSDUCER NUMBER FOR POINT",I4,/,
     $ "THIS POINT WILL BE SKIPPED")
      GO TO 9590
 9564 IM(KK)=NZ(J)
 9562 CONTINUE
      CALL KYBD(2HMS,31,IM(1))
      CALL KYBD(2HMS,11)
      CALL SORT(IYY(1),NIH(1),IH(1),CRH(1),RH(1))
      IF(ISSW(14).LT.0) GOTO 9600
      DO 9570 J=1,ND
      DO 9566 K=1,ND
      IF(NY(K).EQ.NIH(5)) GOTO 9568
 9566 CONTINUE
 9568 CALL KYBD(2HMS,31,IM(K))
      CALL KYBD(2HMS,11)
      CALL BCHK(IBS,IH(5))
C
C     INTERCHANGE WHAT IS IN CORE WITH WHAT IS IN HEADER
C
      CALL SORT(IYY(1),NIH(1),IH(1),CRH(1),RH(1))
      CALL KYBD(2HMS,31,-1,1)
      CALL KYBD(2HMS,21)
 9570 CONTINUE
 9590 CONTINUE
      GOTO 200
 9600 IF(KJ.EQ.1) GOTO 200
      K=KJ-1
C
C     IF EXIT BEFORE ALL POINTS ARE DONE THEN PRINT
C     WHICH HAVE BEEN DONE AND WHICH HAVE NOT.
C
      WRITE(1,9602) IXX(K),IXX(KJ)
 9602 FORMAT(/,"POINTS THROUGH NUMBER",I4," HAVE HAD THE",/,
     1 "TRANSDUCER INFORMATION INTERCHANGED.  POINTS FROM",/,
     2 "NUMBER",I4," ON HAVE NOT BEEN ALTERED")
      GO TO 200
C
C  ***********************************************************
C
C                          EXIT  FROM  Y90
C
```

```
C   ************************************************************
C
 9995 CONTINUE
      CALL KYBD(2HBS,IBSIZE)
      END

**  NO ERRORS**    PROGRAM = 09865      COMMON = 00072
```

```
C
C
C
      SUBROUTINE HDRWD(IK,I)
      I=0
      IF(IK.EQ.10.OR.IK.EQ.24) GOTO 10
      IF(IK.EQ.26.OR.IK.EQ.34) GOTO 10
      IF(IK.EQ.36.OR.IK.EQ.45) GOTO 10
      IF(IK.EQ.46.OR.IK.EQ.49) GOTO 10
      IF(IK.EQ.50.OR.IK.EQ.75) GOTO 10
      IF(IK.EQ.77) GOTO 10
      IF(IK.EQ.19) GOTO 20
      IF(IK.EQ.47.OR.IK.EQ.48) GOTO 20
      IF(IK.EQ.51.OR.IK.EQ.79) GOTO 20
      RETURN
   10 I=1
      RETURN
   20 I=2
      RETURN
      END
```

** NO ERRORS**   PROGRAM = 00143   COMMON = 00000

```
C
C
C
      SUBROUTINE SORT(IYY,NIH,IH,CRH,RH)
      DIMENSION IYY(1),NIH(1),IH(1),CRH(1),RH(1)
      DIMENSION IJ(4)
      DATA IJ/19,47,48,51/
C
C     THIS SUBROUTINE TAKES SPECIFIED HEADER INFO CURRENTLY
C     IN MEMORY AND EXCHANGES IT WITH TEMPORARY ARRAYS NIH & CRH
C
      DO 10 I=1,5
      J=IYY(I)
      IF(J.LE.0) GOTO 20
      IF(J.GE.75) GOTO 5
      DO 2 K=1,4
      IF(J.EQ.IJ(K)) GOTO 3
    2 CONTINUE
    3 IT=IH(J)
      IH(J)=NIH(K)
      NIH(K)=IT
      GO TO 10
    5 J=(J-73)/2
      T=RH(J)
      RH(J)=CRH(1)
      CRH(1)=T
   10 CONTINUE
   20 NIH(5)=IH(51)
      RETURN
      END

**  NO ERRORS**    PROGRAM = 00151      COMMON = 00000
```

```
C
C
C
      SUBROUTINE BCHK(ISYSB,IDATB)
      IF(ISYSB.EQ.IDATB) RETURN
      CALL KYBD(2HBS,IDATB)
      ISYSB=IDATB
      CALL KYBD(2HMS,31,-1,1)
      CALL KYBD(2HMS,11)
      RETURN
      END

**  NO ERRORS**    PROGRAM = 00039      COMMON = 00000
```

```
1355        END$
```

```
2222222 $Y907  T=00004 IS ON CR00103 USING 00058 BLKS R=0512

FTN4
      SUBROUTINE Y0009(INTOT.IPAR)
C
C         THIS  PROGRAM IS STORED UNDER $Y907
C
C***********************************************************************
C
C       PROGRAMMER:  R.J.ALLEMANG
C                    MAIL LOCATION # 72
C                    UNIVERSITY OF CINCINNATI
C                    CINCINNATI, OHIO  45221
C                    513-475-6670
C
C       REVISION DATE:  DEC 17,1979
C
C***********************************************************************
      DIMENSION IPAR(6),LINE(36),LINE1(35),IZ(10),INQ(6)
     1,IDIV(1),ICMMD(24),IH(1),IX1(1),IY1(1),IDX(1),IDY(1)
     2,IC1(1),IPTCM(1),LABEL(20),IPOINT(1)
      EQUIVALENCE (LINE(2),LINE1)
      COMMON ICOMM,MANRE,MDVA,BETA,IBLS,IT(5),ID(3),IP,NUMPT
     1,NM,ICON,NCOM,XXX(3,10),IX(3,10),IC(10),NMP,XR(3),A(2,3)
     2,O(3),IB(10),NCN(10),SF(2),XXA(2,3),YYA(2,3)
     3,FSHFT,DF,MCF,IZR,IL,IPAR1,IPAR2,IPAR3,IPAR4,IPAR5,IPAR6
     4,IFLAG,NS,NE,RMM(10),FRQ(10),ZETA(10)
      EXTERNAL HDR8,DTAD0,NMAX
      DATA ICMMD/2HD ,2HV ,2H% ,2HEX,2H: ,
     12HM ,2H_ ,2HRO,2HA-,2HAM,
     22HCH,2HSP,2HX<,
     32HX>,2HCV,2H< ,2HB ,2HL ,
     42HW ,2HI ,2HK ,2HA+,2H/L,
     52H/./
C***********************************************************************
C         UNIVERSITY OF CINCINNATI/LEUVEN MODAL ANALYSIS PROGRAM
C
C          PLOTTING PROGRAM   TEK  4012
C***********************************************************************
      IBELL=7B
      IPAGE=15414B
      CALL SETAD(HDR8,IH,-8,0)
      ICOMM=0
      IBS=1024
      CALL KYBD(2HBS,IBS,0)
      CALL GETI(NMAX,IBLM)
      ION=IBLM-1
      ICM=ION-1
      IBM=2
      I=ION*IBS+270
      CALL SETAD(DTAD0,IPTCM,I,-1)
      CALL RWCOM(0)
C
C         IF INITIALIZATION IS REQUIRED, LOAD Y 91
C
      IF(ICOMM.EQ.12345)GO TO 900
      CALL KYBD(2HMS,38,-7,1)
      CALL OVLD(9)
  900 CONTINUE
      CALL SETAD(DTAD0,IX1,0,-1)
```

```
      CALL SETAD(DTAD0,IY1,256,-1)
      CALL SETAD(DTAD0,IDX,512,-1)
      CALL SETAD(DTAD0,IDY,768,-1)
      CALL SETAD(DTAD0,IC1,1024,-1)
      CALL SETAD(DTAD0,IDIV,1536,-1)
      CALL SETAD(DTAD0,IPOINT,1600,-1)
      NPD=IDIV(21)
      IFLG7=0
      MXOFF=IDIV(22)
      MYOFF=IDIV(23)
      MCSIZE=IDIV(24)
      MP1=IDIV(25)
      MP2=IDIV(26)
      IFLG7=IDIV(27)
      IF(IFLAG.EQ.1)GO TO 1130
C**************************************************************************
C        START OF MONITOR
C**************************************************************************
 1000 WRITE(1,1010)IBELL
 1010 FORMAT("*",A2)
      I=ISWR(177677B,0,0)
      IPAR1=-9999
      IPAR2=-9999
      IPAR3=-9999
      IPAR4=-9999
      IPAR5=-9999
      IPAR6=-9999
 1020 DO 1030 I=1,36
 1030 LINE(I)=2H,,
 1040 CALL TTYIN(LINE)
 1042 CALL TEST(1,IST,LOG)
      IF(IST.LT.0)GO TO 1042
      CALL CODE
      READ(LINE,1120)IL
      IF(ICOMM.EQ.12345)GO TO 1115
C
C        FUT A CHECK FOR ANY COMMANDS THAT ARE NOT TO BE
C             EXECUTED UNLESS ENOUGH SET-UP IS PRESENT
C
 1115 CONTINUE
 1120 FORMAT(A2)
      CALL CODE
      READ(LINE1,*)IPAR1,IPAR2,IPAR3,IPAR4,IPAR5,IPAR6
C**************************************************************************
C        MONITOR COMMAND TABLE
C**************************************************************************
 1130 IFLAG=0
      CALL RWCOM(1)
      IF(IL.EQ.2H##)GO TO 1000
      NCMMD=24
      DO 1138  I=1,NCMMD
      IF(IL.EQ.ICMMD(I))GO TO 1144
 1138 CONTINUE
 1139 WRITE(1,1140)
 1140 FORMAT(/,"ERROR-ILLEGAL COMMAND")
      GO TO 1000
 1144 IF(I.GT.10)GO TO 1146
      GO TO (9004,9004,9004,9004,9004,9004,9004,9004,9004,9004),I
 1146 I=I-10
      IF(I.GT.10)GO TO 1148
```

```
      GO TO (9004,9004,9004,9004,9004,9995,8000,2000,9002,9001),I
 1148 I=I-10
      GO TO (9001,9003,9008,7000),I
C
C       ENTER DATA TO SET UP POINT LABELING OF PLOT
C
 7000 CONTINUE
      IF(IPAR1.EQ.-9999)IPAR1=100
      IF(IPAR2.EQ.-9999)IPAR2=100
      IF(IPAR3.EQ.-9999)IPAR3=100
      IF(IPAR4.EQ.-9999)IPAR4=1
      IF(IPAR5.EQ.-9999)IPAR5=250
      IFLG7=1
      MXOFF=IPAR1
      MYOFF=IPAR2
      MCSIZE=IPAR3
      MP1=IPAR4
      MP2=IPAR5
      GO TO 1000
 2000 CONTINUE
      IF(IPAR.EQ.37)GO TO 9005
      IF(IPAR.EQ.10)GO TO 9006
C***********************************************************************
C                 PLOTS MODE SHAPES ON THE TEK 4012
C***********************************************************************
 8000 CONTINUE
      IF(IPAR1.EQ.37)GO TO 9005
      IF(IPAR1.EQ.10)GO TO 9006
      IJJ=IPAR2
      IF(IPAR2.EQ.-9999)IPAR2=0
      ITEK=6B
      DSHTEK=9.
      XTEK=390.
      YTEK=390.
      TEKSCL=84.0
      IF(ISSW(15).LT.0)GO TO 8008
      WRITE(1,8009)IPAGE
 8009 FORMAT(A2)
 8008 CONTINUE
      XCENT=XTEK
      YCENT=YTEK
      PSCAL=TEKSCL
      DASH=DSHTEK
      IDEV=ITEK
      CALL FNDLU(IDEV,LU)
      IF(LU.EQ.0)WRITE(1,8236)IBELL
 8236 FORMAT(/,"ERROR-INVALID LOGICAL UNIT",A2)
      IF(LU.EQ.0)GO TO 1000
      IF(NPD.LE.2)GO TO 8110
      IF(NPD.GT.500)GO TO 8110
C
C          INITIALIZE
C
      IF(IPAR2.LE.0)IJJ=1
      IF(IPAR2.GT.20)IJJ=1
 8045 CONTINUE
C
C          PLOT LOOP
C
C             SWITCH 12   SOLID UNDEFORMED LINES
```

```
C            SWITCH 13   ABORT POINT LABELING
C            SWITCH 14   ABORT PLOT
C
      DO 8100 I=1,NPD
C
C          SWITCH 14 TO ABORT PLOT
C
      IF(ISSW(14).LT.0)GO TO 1000
      J=IABS(IC1(I))
      JGARY=1
      IF(IC1(I).LT.0)JGARY=-1
      IJX=FLOAT(IX1(J))/PSCAL+XCENT
      IJY=FLOAT(IY1(J))/PSCAL+YCENT
      IF(I.EQ.1)IXOLD=IJX
      IF(I.EQ.1)IYOLD=IJY
      JX=IJX+IDX(J)/(IDIV(IJJ)*PSCAL)
      JY=IJY+IDY(J)/(IDIV(IJJ)*PSCAL)
      IF(IPAR2.NE.0)GO TO 8050
C
C        PLOT UNDEFORMED SHAPE
C
      IF(ISSW(12).LT.0)GO TO 8060
C
C       SET SWITCH 12 FOR UNDEFORMED SOLID LINES
C
      IF(JGARY.EQ.-1)GO TO 8060
      CALL DOT(IXOLD,IYOLD,IJX,IJY,DASH,LU)
      GO TO 8062
 8060 WRITE(LU)JGARY,1,IJX,IJY
 8062 CONTINUE
      IXOLD=IJX
      IYOLD=IJY
      GO TO 8100
C
C           PLOT MAXIMUM DEFORMED SHAPE
C
 8050 WRITE(LU)JGARY ,1,JX,JY
 8100 CONTINUE
      IF(IPAR2.LT.0)IJJ=IJJ+2
      IF((IPAR2.LT.0).AND.(IJJ.LT.12))GO TO 8045
      IFLG7=0
 8108 CONTINUE
      JGARY=-1
      WRITE(LU)JGARY,1,0,30
      WRITE(1,8109)IT,FRQ(NMP)
 8109 FORMAT(2X,5A2,4X,F10.3)
      GO TO 1000
 8110 CONTINUE
      WRITE(1,8111)
 8111 FORMAT(/,"ERROR-DISPLAY NOT PREVIOUSLY CALCULATED",/)
      GO TO 1000
C**********************************************************************
C         EXIT TO OTHER OVERLAYS
C**********************************************************************
 9001 I=1
      GO TO 9900
 9002 I=2
      GO TO 9900
 9003 I=3
      GO TO 9900
```

```
9004 I=4
     GO TO 9900
9005 I=5
     GO TO 9900
9006 I=6
     GO TO 9900
9008 I=8
     GO TO 9900
9900 CONTINUE
     IFLAG=1
     CALL RWCOM(1)
     CALL KYBD(2HMS,38,I)
     CALL OVLD(9)
9995 CONTINUE
     1L=2H**
     IF(ICOMM.EQ.12345)CALL RWCOM(1)
     CALL KYBD(2HBS,IBS,0)
     RETURN
     END
     END$
```

```
$Y906  T=00004 IS ON CR00103 USING 00058 BLKS R=0512

FTN4
      SUBROUTINE Y0009(INTOT,IPAR)
C
C         THIS PROGRAM IS STORED UNDER $Y906
C
C***********************************************************************
C
C        PROGRAMMER:  R.J.ALLEMANG
C                     MAIL LOCATION # 72
C                     UNIVERSITY OF CINCINNATI
C                     CINCINNATI, OHIO  45221
C                     513-475-6670
C
C        REVISION DATE:   DEC 17, 1979
C
C***********************************************************************
      DIMENSION IPAR(6),LINE(36),LINE1(35),IZ(10),INQ(6)
     1,IDIV(1),ICMMD(24),IH(1),IX1(1),IY1(1),IDX(1),IDY(1)
     2,IC1(1),IPTCM(1),LABEL(20),IPOINT(1)
      EQUIVALENCE (LINE(2),LINE1)
      COMMON ICOMM,MANRE,MDVA,BETA,IBLS,IT(5),ID(3),IP,NUMPT
     1,NM,ICON,NCOM,XXX(3,10),IX(3,10),IC(10),NMP,XR(3),A(2,3)
     2,O(3),IB(10),NCN(10),SF(2),XXA(2,3),YYA(2,3)
     3,FSHFT,DF,MCF,IZR,IL,IPAR1,IPAR2,IPAR3,IPAR4,IPAR5,IPAR6
     4,IFLAG,NS,NE,RMM(10),FRQ(10),ZETA(10)
      EXTERNAL HDR8,DTAD0,NMAX
      DATA ICMMD/2HD ,2HV ,2H% ,2HEX,2H: ,
     12HM ,2H_ ,2HRO,2HA-,2HAM,
     22HCH,2HSP,2HX<,
     32HX>,2HCV,2H( ,2HB ,2HL ,
     42HW ,2HI ,2HK ,2HA+,2H/L,
     52H/./
C***********************************************************************
C         UNIVERSITY OF CINCINNATI/LEUVEN MODAL ANALYSIS PROGRAM
C
C          PLOTTING PROGRAM  HP 7210
C***********************************************************************
      IBELL=7B
      IPAGE=15414B
      CALL SETAD(HDR8,IH,-8,0)
      ICOMM=0
      IBS=1024
      CALL KYBD(2HBS,IBS,0)
      CALL GETI(NMAX,IBLM)
      ION=IBLM-1
      ICM=ION-1
      IBM=2
      I=ION*IBS+270
      CALL SETAD(DTAD0,IPTCM,I,-1)
      CALL RWCOM(0)
C
C         IF INITIALIZATION IS REQUIRED, LOAD Y 91
C
      IF(ICOMM.EQ.12345)GO TO 900
      CALL KYBD(2HMS,38,-6,1)
      CALL OVLD(9)
  900 CONTINUE
      CALL SETAD(DTAD0,IX1,0,-1)
```

```
      CALL SETAD(DTAD0,IY1,256,-1)
      CALL SETAD(DTAD0,IDX,512,-1)
      CALL SETAD(DTAD0,IDY,768,-1)
      CALL SETAD(DTAD0,IC1,1024,-1)
      CALL SETAD(DTAD0,IDIV,1536,-1)
      CALL SETAD(DTAD0,IPOINT,1600,-1)
      NPD=IDIV(21)
      IFLG7=0
      MXOFF=IDIV(22)
      MYOFF=IDIV(23)
      MCSIZE=IDIV(24)
      MP1=IDIV(25)
      MP2=IDIV(26)
      IFLG7=IDIV(27)
      IF(IFLAG.EQ.1)GO TO 1130
C***********************************************************************
C         START OF MONITOR
C***********************************************************************
 1000 WRITE(1,1010)IBELL
 1010 FORMAT("*",A2)
      I=ISWR(177677B,0,0)
      IPAR1=-9999
      IPAR2=-9999
      IPAR3=-9999
      IPAR4=-9999
      IPAR5=-9999
      IPAR6=-9999
 1020 DO 1030 I=1,36
 1030 LINE(I)=2H,,
 1040 CALL TTYIN(LINE)
 1042 CALL TEST(1,IST,LOG)
      IF(IST.LT.0)GO TO 1042
      CALL CODE
      READ(LINE,1120)IL
      IF(ICOMM.EQ.12345)GO TO 1115
C
C         PUT A CHECK FOR ANY COMMANDS THAT ARE NOT TO BE
C             EXECUTED UNLESS ENOUGH SET-UP IS PRESENT
C
 1115 CONTINUE
 1120 FORMAT(A2)
      CALL CODE
      READ(LINE1,*)IPAR1,IPAR2,IPAR3,IPAR4,IPAR5,IPAR6
C***********************************************************************
C         MONITOR COMMAND TABLE
C***********************************************************************
 1130 IFLAG=0
      CALL RWCOM(1)
      IF(IL.EQ.2H##)GO TO 1000
      NCMMD=24
      DO 1138  I=1,NCMMD
      IF(IL.EQ.ICMMD(I))GO TO 1144
 1138 CONTINUE
 1139 WRITE(1,1140)
 1140 FORMAT(/,"ERROR-ILLEGAL COMMAND")
      GO TO 1000
 1144 IF(I.GT.10)GO TO 1146
      GO TO (9004,9004,9004,9004,9004,9004,9004,9004,9004,9004),I
 1146 I=I-10
      IF(I.GT.10)GO TO 1148
```

```
      GO TO (9004,9004,9004,9004,9004,9995,8000,8200,9002,9001),I
 1148 I=I-10
      GO TO (9001,9003,9008,7000),I
C
C      ENTER DATA TO SET UP POINT LABELING OF PLOT
C
 7000 CONTINUE
      IF(IPAR1.EQ.-9999)IPAR1=100
      IF(IPAR2.EQ.-9999)IPAR2=100
      IF(IPAR3.EQ.-9999)IPAR3=100
      IF(IPAR4.EQ.-9999)IPAR4=1
      IF(IPAR5.EQ.-9999)IPAR5=250
      IFLG7=1
      MXOFF=IPAR1
      MYOFF=IPAR2
      MCSIZE=IPAR3
      MP1=IPAR4
      MP2=IPAR5
      GO TO 1000
C*********************************************************************
C                 PLOTS MODE SHAPES ON THE HP  7210
C*********************************************************************
 8000 CONTINUE
      IF(IPAR1.EQ.37)GO TO 9005
      IF(IPAR1.EQ.6)GO TO 9007
      IJJ=IPAR2
      IF(IPAR2.EQ.-9999)IPAR2=0
      IPLOT=10B
      XPLOT=5000.
      YPLOT=5000.
      DSHPLT=100.
      PLTSCL=6.56
 8010 CONTINUE
      XCENT=XPLOT
      YCENT=YPLOT
      PSCAL=PLTSCL
      DASH=DSHPLT
      IDEV=IPLOT
      CALL FNDLU(IDEV,LU)
      IF(LU.EQ.0)WRITE(1,8236)
      IF(LU.EQ.0)GO TO 1000
      IF(NPD.LE.2)GO TO 8110
      IF(NPD.GT.500)GO TO 8110
C
C       INITIALIZE
C
      IF(IPAR2.LE.0)IJJ=1
      IF(IPAR2.GT.20)IJJ=1
C
C        ARRAY TO FLAG POINTS ALREADY LABELED
C
      DO 8038  I=1,250
 8038 IPOINT(I)=1
      DO 8040 I=MP1,MP2
 8040 IPOINT(I)=0
 8045 CONTINUE
C
C        PLOT LOOP
C
C          SWITCH 12   SOLID UNDEFORMED LINES
```

```
C           SWITCH 13   ABORT POINT LABELING
C           SWITCH 14   ABORT PLOT
C
      DO 8100 I=1,NPD
C
C         SWITCH 14 TO ABORT PLOT
C
      IF(ISSW(14).LT.0)GO TO 1000
      J=IABS(IC1(I))
      JGARY=1
      IF(IC1(I).LT.0)JGARY=-1
      IJX=FLOAT(IX1(J))/PSCAL+XCENT
      IJY=FLOAT(IY1(J))/PSCAL+YCENT
      IF(I.EQ.1)IXOLD=IJX
      IF(I.EQ.1)IYOLD=IJY
      JX=IJX+IDX(J)/(IDIV(IJJ)*PSCAL)
      JY=IJY+IDY(J)/(IDIV(IJJ)*PSCAL)
      IF(IPAR2.NE.0)GO TO 8050
C
C            PLOT UNDEFORMED SHAPE
C
      IF(ISSW(12).LT.0)GO TO 8060
C
C      SET SWITCH 12 FOR UNDEFORMED SOLID LINES
C
      IF(JGARY.EQ.-1)GO TO 8060
      CALL DOT(IXOLD,IYOLD,IJX,IJY,DASH,LU)
      GO TO 8062
 8060 WRITE(LU)JGARY ,1,IJX,IJY
C
C      POINT LABELING
C
      IF(IFLG7.EQ.0)GO TO 8062
C
C        ABORT POINT LABELING   SWITCH 13
C
      IF(ISSW(13).LT.0)GO TO 8062
      IF(IPOINT(J).EQ.1)GO TO 8062
      THETA=0.0
      IRAD=20
      DO 8055 KK=1,10
      JXXX=IJX+IRAD*SIN(THETA)
      JYYY=IJY+IRAD*COS(THETA)
      THETA=THETA+0.628312
      WRITE(LU)1,1,JXXX,JYYY
 8055 CONTINUE
      WRITE(LU)-1,-1,MXOFF,MYOFF
      WRITE(LU,8065)MCSIZE,0,0,MCSIZE,J
 8068 CONTINUE
      WRITE(LU)-1,1,IJX,IJY
 8065 FORMAT(4I5,I3)
      IPOINT(J)=1
 8062 CONTINUE
      IXOLD=IJX
      IYOLD=IJY
      GO TO 8100
C
C            PLOT MAXIMUM DEFORMED SHAPE
C
 8050 WRITE(LU)JGARY ,1,JX,JY
```

```
      GO TO 8100
 8100 CONTINUE
      IF(IPAR2.LT.0)IJJ=IJJ+2
      IF((IPAR2.LT.0).AND.(IJJ.LT.12))GO TO 8045
      IFLG7=0
 8108 CONTINUE
C
C        PRINT TEST I.D. AND MODE FREQUENCY
C
      IF(NMP.EQ.0)GO TO 1000
 8155 CONTINUE
      WRITE(LU)-1,1,100,7000
      WRITE(LU,8156)200,0,0,200,IT
 8156 FORMAT(4I5,5A2)
      WRITE(LU)-1,1,100,6500
      WRITE(LU,8157)200,0,0,200,FRQ(NMP)
 8157 FORMAT(4I5,F10.3)
      GO TO 1000
 8110 CONTINUE
      WRITE(1,8111)
 8111 FORMAT(/,"ERROR-DISPLAY NOT PREVIOUSLY CALCULATED",/)
      GO TO 1000
C***********************************************************************
C          CODE LABELS MODE SHAPE PLOTS
C***********************************************************************
 8200 CONTINUE
      IF(IPAR1.EQ.37)GO TO 9005
      IDEV=10B
      CALL FNDLU(IDEV,LU)
      IF(LU.EQ.0)WRITE(1,8236)
      IF(LU.EQ.0)GO TO 1000
      IF(IPAR4.NE.-9999)GO TO 8210
      IPAR4=200
      IF(IPAR3.NE.-9999)GO TO 8210
      IPAR3=700.0
      IF(IPAR2.NE.-9999)GO TO 8210
      IPAR2=350.0
C
C              IPAR1 = DEVICE  THAT THE LABEL IS TO BE PRINTED ON
C              IPAR2 = STARTING X POSITION OF LABEL
C              IPAR3 = STARTING Y POSITION OF LABEL
C              IPAR4 = SIZE OF CHARACTERS(IPAR4 X IPAR4)
C
 8210 CONTINUE
      IPAR2=IPAR2*10
      IPAR3=IPAR3*10
      WRITE(LU)-1,1,IPAR2,IPAR3
      DO 8226 I=1,20
 8226 LABEL(I)=2H
      WRITE(1,8230)IBELL
 8230 FORMAT(/,"ENTER LABEL:",A2,/)
      READ(1,8235)(LABEL(I),I=1,20)
      CALL TEST(1,ISTAT,LOGX)
      LOGX=(LOGX+1)/2
 8235 FORMAT(20A2)
      IF(LABEL(1).EQ.2H/ )GO TO 1000
 8236 FORMAT(/,"ERROR-INVALID LOGICAL UNIT ")
      WRITE(LU)-1,1,IPAR2,IPAR3
      WRITE(LU,8240)IPAR4,0,0,IPAR4,(LABEL(I),I=1,LOGX)
 8240 FORMAT(4I5,20A2)
```

```
      IPAR3=IPAR3-IPAR4*12/10
      GO TO 8210
C***********************************************************************
C         EXIT TO OTHER OVERLAYS
C***********************************************************************
 9001 I=1
      GO TO 9900
 9002 I=2
      GO TO 9900
 9003 I=3
      GO TO 9900
 9004 I=4
      GO TO 9900
 9005 I=5
      GO TO 9900
 9007 I=7
      GO TO 9900
 9008 I=8
      GO TO 9900
 9900 CONTINUE
      IFLAG=1
      CALL RWCOM(1)
      CALL KYBD(2HMS,38,I)
      CALL OVLD(9)
 9995 CONTINUE
      IL=2H**
      IF(ICOMM.EQ.12345)CALL RWCOM(1)
      CALL KYBD(2HBS,IBS,0)
      RETURN
      END
      END$
```

```
$Y905  T=00004 IS ON CR00103 USING 00058 BLKS R=0512

FTN4
      SUBROUTINE Y0009(INTOT,IPAR)
C
C        THIS PROGRAM IS STORED UNDER $Y905
C
C*****************************************************************************
C
C       PROGRAMMER:  R.J.ALLEMANG
C                    MAIL LOCATION # 72
C                    UNIVERSITY OF CINCINNATI
C                    CINCINNATI, OHIO  45221
C                    513-475-6670
C
C       REVISION DATE:   DEC 17, 1979
C
C*****************************************************************************
      DIMENSION IPAR(6),LINE(36),LINE1(35),IZ(10),INQ(6)
     1,IDIV(1),ICMMD(24),IH(1),IX1(1),IY1(1),IDX(1),IDY(1)
     2,IC1(1),IPTCM(1),LABEL(20),IPOINT(1)
      EQUIVALENCE (LINE(2),LINE1)
      COMMON ICOMM,MANRE,MDVA,BETA,IBLS,IT(5),ID(3),IP,NUMPT
     1,NM,ICON,NCOM,XXX(3,10),IX(3,10),IC(10),NMP,XR(3),A(2,3)
     2,O(3),IB(10),NCN(10),SF(2),XXA(2,3),YYA(2,3)
     3,FSHFT,DF,MCF,IZR,IL,IPAR1,IPAR2,IPAR3,IPAR4,IPAR5,IPAR6
     4,IFLAG,NS,NE,RMM(10),FRQ(10),ZETA(10)
      EXTERNAL HDR8,DTAD0,NMAX
      DATA ICMMD/2HD ,2HV ,2H% ,2HEX,2H: ,
     12HM ,2H_ ,2HRO,2HA-,2HAM,
     22HCH,2HSP,2HX<,
     32HX>,2HCV,2H< ,2HB ,2HL ,
     42HW ,2HI ,2HK ,2HA+,2H/L,
     52H/./
C*****************************************************************************
C        UNIVERSITY OF CINCINNATI/LEUVEN MODAL ANALYSIS PROGRAM
C
C         PLOTTING PROGRAM  HP  9872
C*****************************************************************************
      IPAGE=15414B
      IBELL=7B
      CALL SETAD(HDR8,IH,-8,0)
      ICOMM=0
      IBS=1024
      CALL KYBD(2HBS,IBS,0)
      CALL GETI(NMAX,IBLM)
      ION=IBLM-1
      ICM=ION-1
      IBM=2
      I=ION*IBS+270
      CALL SETAD(DTAD0,IPTCM,I,-1)
      CALL RWCOM(0)
C
C        IF INITIALIZATION IS REQUIRED, LOAD Y 91
C
      IF(ICOMM.EQ.12345)GO TO 900
      CALL KYBD(2HMS,38,-5,1)
      CALL OVLD(9)
  900 CONTINUE
      CALL SETAD(DTAD0,IX1,0,-1)
```

```
      CALL SETAD(DTAD0,IY1,256,-1)
      CALL SETAD(DTAD0,IDX,512,-1)
      CALL SETAD(DTAD0,IDY,768,-1)
      CALL SETAD(DTAD0,IC1,1024,-1)
      CALL SETAD(DTAD0,IDIV,1536,-1)
      CALL SETAD(DTAD0,IPOINT,1600,-1)
      NPD=IDIV(21)
      IFLG7=0
      MXOFF=IDIV(22)
      MYOFF=IDIV(23)
      MCSIZE=IDIV(24)
      MP1=IDIV(25)
      MP2=IDIV(26)
      IFLG7=IDIV(27)
      IF(IFLAG.EQ.1)GO TO 1130
C***********************************************************************
C       START OF MONITOR
C***********************************************************************
 1000 WRITE(1,1010)IBELL
 1010 FORMAT("*",A2)
      I=ISWR(177677B,0,0)
      IPAR1=-9999
      IPAR2=-9999
      IPAR3=-9999
      IPAR4=-9999
      IPAR5=-9999
      IPAR6=-9999
 1020 DO 1030 I=1,36
 1030 LINE(I)=2H,,
 1040 CALL TTYIN(LINE)
 1042 CALL TEST(1,IST,LOG)
      IF(IST.LT.0)GO TO 1042
      CALL CODE
      READ(LINE,1120)IL
      IF(ICOMM.EQ.12345)GO TO 1115
C
C       PUT A CHECK FOR ANY COMMANDS THAT ARE NOT TO BE
C           EXECUTED UNLESS ENOUGH SET-UP IS PRESENT
C
 1115 CONTINUE
 1120 FORMAT(A2)
      CALL CODE
      READ(LINE1,*)IPAR1,IPAR2,IPAR3,IPAR4,IPAR5,IPAR6
C***********************************************************************
C       MONITOR COMMAND TABLE
C***********************************************************************
 1130 IFLAG=0
      CALL RWCOM(1)
      IF(IL.EQ.2H##)GO TO 1000
      NCMMD=24
      DO 1138  I=1,NCMMD
      IF(IL.EQ.ICMMD(I))GO TO 1144
 1138 CONTINUE
 1139 WRITE(1,1140)
 1140 FORMAT(/,"ERROR-ILLEGAL COMMAND")
      GO TO 1000
 1144 IF(I.GT.10)GO TO 1146
      GO TO (9004,9004,9004,9004,9004,9004,9004,9004,9004,9004),I
 1146 I=I-10
      IF(I.GT.10)GO TO 1148
```

```
      GO TO (9004,9004,9004,9004,9004,9995,8000,8200,9002,9001),I
 1148 I=I-10
      GO TO (9001,9003,9008,7000),I
C
C      ENTER DATA TO SET UP POINT LABELING OF PLOT
C
 7000 CONTINUE
      IF(IPAR1.EQ.-9999)IPAR1=100
      IF(IPAR2.EQ.-9999)IPAR2=100
      IF(IPAR3.EQ.-9999)IPAR3=100
      IF(IPAR4.EQ.-9999)IPAR4=1
      IF(IPAR5.EQ.-9999)IPAR5=250
      IFLG7=1
      MXOFF=IPAR1
      MYOFF=IPAR2
      MCSIZE=IPAR3
      MP1=IPAR4
      MP2=IPAR5
      GO TO 1000
C***********************************************************************
C                 PLOTS MODE SHAPES ON THE HP  9872
C***********************************************************************
 8000 CONTINUE
      IF(IPAR1.EQ.10)GO TO 9006
      IF(IPAR1.EQ.6)GO TO 9007
      IJJ=IPAR2
      IF(IPAR2.EQ.-9999)IPAR2=0
      IPLT=37B
      XPLT=5500.0
      YPLT=3500.0
      PLTSKL=9.28
 8020 CONTINUE
      XCENT=XPLT
      YCENT=YPLT
      PSCAL=PLTSKL
      ICOLOR=1
      IF(IPAR3.NE.-9999)ICOLOR=IPAR3
      IDEV=IPLT
C
C      CHECK TO FIND LOGICAL UNIT
C
      CALL FNDLU(IDEV,LU)
      IF(LU.EQ.0)WRITE(1,8236)
      IF(LU.EQ.0)GO TO 1000
      IF(NPD.LE.2)GO TO 8110
      IF(NPD.GT.500)GO TO 8110
C
C         INITIALIZE AND SELECT PEN COLOR
C
      WRITE(LU,8035)ICOLOR
 8035 FORMAT("IP0,0,11000,8000"/"PU"/"IW0,0,11000,8000"/"SP"I6/
     1"LT")
      IF(IPAR2.LE.0)IJJ=1
      IF(IPAR2.GT.20)IJJ=1
C
C         ARRAY TO FLAG POINTS ALREADY LABELED
C
      DO 8038  I=1,250
 8038 IPOINT(I)=1
      DO 8040 I=MP1,MP2
```

```
 8040 IPOINT(I)=0
 8045 CONTINUE
C
C         PLOT LOOP
C
C            SWITCH 12   SOLID UNDEFORMED LINES
C            SWITCH 13   ABORT POINT LABELING
C            SWITCH 14   ABORT PLOT
C
      DO 8100 I=1,NPD
C
C         SWITCH 14 TO ABORT PLOT
C
      IF(ISSW(14).LT.0)GO TO 1000
      J=IABS(IC1(I))
      JGARY=1
      IF(IC1(I).LT.0)JGARY=-1
      IJX=FLOAT(IX1(J))/PSCAL+XCENT
      IJY=FLOAT(IY1(J))/PSCAL+YCENT
      IF(I.EQ.1)IXOLD=IJX
      IF(I.EQ.1)IYOLD=IJY
      JX=IJX+IDX(J)/(IDIV(IJJ)*PSCAL)
      JY=IJY+IDY(J)/(IDIV(IJJ)*PSCAL)
      IF(JGARY.EQ.-1)WRITE(LU,8075)
 8075 FORMAT("PU")
      IF(IPAR2.NE.0)GO TO 8080
C
C       SWITCH 12 ON: SOLID LINES
C
      IF(ISSW(12).GE.0)WRITE(LU,8072)
 8072 FORMAT("LT2,1.0")
C
C         UNDEFORMED SHAPE
C
      WRITE(LU,8078)IJX,IJY
 8078 FORMAT("SM."/"PA",I6,",",I6/"PD"/"SM")
      IF(IPOINT(J).EQ.1)GO TO 8100
      IF(IFLG7.EQ.0)GO TO 8100
C
C       SWITCH 13 ON: ABORT POINT NUMBER
C
      IF(ISSW(13).LT.0)GO TO 8100
      WRITE(LU,8013)MXOFF,MYOFF
 8013 FORMAT("PU"/"PR",I6,",",I6/)
      IF(J.LT.10)WRITE(LU,8015)J
      IF((J.GE.10).AND.(J.LT.100))WRITE(LU,8016)J
      IF(J.GE.100)WRITE(LU,8017)J
 8015 FORMAT("LB",I1)
 8016 FORMAT("LB",I2)
 8017 FORMAT("LB",I3)
      WRITE(LU,8430)
      WRITE(LU,8014)IJX,IJY
 8014 FORMAT("PU"/"PA",I6,",",I6/"PD")
      IPOINT(J)=1
      GO TO 8100
 8080 CONTINUE
C
C         DEFORMED SHAPE
C
      WRITE(LU,8078)JX,JY
```

```
 8100 CONTINUE
      IF(IPAR2.LT.0)IJJ=IJJ+2
      IF((IPAR2.LT.0).AND.(IJJ.LT.12))GO TO 8045
      IFLG7=0
 8108 CONTINUE
C
C          PRINT TEST I.D. AND MODE FREQUENCY
C
      IF(NMP.EQ.0)GO TO 1000
      WRITE(LU,8109)IT,FRQ(NMP)
 8109 FORMAT("PU"/"PA1000,7300"/
     1"LBTEST  ",5A2/" "/F10.3," HERTZ")
      WRITE(LU,8430)
       GO TO 1000
 8110 CONTINUE
      WRITE(1,8111)
 8111 FORMAT(/,"ERROR-DISPLAY NOT PREVIOUSLY CALCULATED",/)
      GO TO 1000
C**********************************************************************
C          CODE LABELS MODE SHAPE PLOTS
C**********************************************************************
 8200 CONTINUE
      IF(IPAR1.EQ.10)GO TO 9006
      IDEV=37B
      CALL FNDLU(IDEV,LU)
      IF(LU.EQ.0)WRITE(1,8236)
      IF(LU.EQ.0)GO TO 1000
C
C              IPAR1 = DEVICE  THAT THE LABEL IS TO BE PRINTED ON
C              IPAR2 = STARTING X POSITION OF LABEL
C              IPAR3 = STARTING Y POSITION OF LABEL
C              IPAR4 = SIZE OF CHARACTERS(IPAR4 X IPAR4)
C
 8230 FORMAT(/,"ENTER LABEL",A2,/)
 8235 FORMAT(20A2)
 8236 FORMAT(/,"ERROR-INVALID LOGICAL UNIT ")
 8400 CONTINUE
      ICOLOR=IPAR4
      IF(IPAR4.NE.-9999)GO TO 8410
      ICOLOR=1
      IF(IPAR3.NE.-9999)GO TO 8410
      IPAR3=7300
      IF(IPAR2.NE.-9999)GO TO 8410
      IPAR2=5000
 8410 CONTINUE
      WRITE(LU,8420)ICOLOR,IPAR2,IPAR3
 8420 FORMAT("IP0,0,11000,8000"/"PU"/"IW0,0,11000,8000"/"LT"/
     1"SP"I6/"PA",I6,",",I6)
 8422 DO 8425 I=1,20
 8425 LABEL(I)=2H
      WRITE(1,8230)IBELL
      READ(1,8235)(LABEL(I),I=1,20)
      CALL TEST(1,ISTAT,LOGX)
      LOGX=(LOGX+1)/2
      IF(LABEL(1).EQ.2H/ )WRITE(LU,8430)
      IF(LABEL(1).EQ.2H/ )GO TO 1000
C
C          CONTROL C TO TERMINATE  HP  9872
C
 8430 FORMAT("")
```

```
      WRITE(LU,8440)(LABEL(I),I=1,LOGX)
 8440 FORMAT("LB",20A2)
      WRITE(LU,8430)
      GO TO 8422
C*************************************************************************
C        EXIT TO OTHER OVERLAYS
C*************************************************************************
 9001 I=1
      GO TO 9900
 9002 I=2
      GO TO 9900
 9003 I=3
      GO TO 9900
 9004 I=4
      GO TO 9900
 9005 I=5
      GO TO 9900
 9006 I=6
      GO TO 9900
 9007 I=7
      GO TO 9900
 9008 I=8
      GO TO 9900
 9900 CONTINUE
      IFLAG=1
      CALL RWCOM(1)
      CALL KYBD(2HMS,38,I)
      CALL OVLD(9)
 9995 CONTINUE
      IL=2H**
      IF(ICOMM.EQ.12345)CALL RWCOM(1)
      CALL KYBD(2HBS,IBS,0)
      RETURN
      END
      END$
```

```
$Y901  T=00004 IS ON CR00103 USING 00082 BLKS R=0702

FTN4
      SUBROUTINE Y0009(INTOT,IPAR)
C
C         THIS PROGRAM IS STORED UNDER $Y901
C
C*************************************************************************
C
C        PROGRAMMER:  R.J.ALLEMANG
C                     MAIL LOCATION # 72
C                     UNIVERSITY OF CINCINNATI
C                     CINCINNATI, OHIO  45221
C                     513-475-6670
C
C        REVISION DATE:  DEC 17,1979
C
C*************************************************************************
      DIMENSION IPAR(6),LINE(36),LINE1(35),IZ(10),INQ(6)
     1,IDIV(1),ICMMD(24),IH(1),IX1(1),IY1(1),IDX(1),IDY(1)
     2,IC1(1),IPTCM(1),RH(1)
      EQUIVALENCE (LINE(2),LINE1)
      COMMON ICOMM,MANRE,MDVA,BETA,IBLS,IT(5),ID(3),IP,NUMPT
     1,NM,ICON,NCOM,XXX(3,10),IX(3,10),IC(10),NMP,XR(3),A(2,3)
     2,O(3),IB(10),NCN(10),SF(2),XXA(2,3),YYA(2,3)
     3,FSHFT,DF,MCF,IZR,IL,IPAR1,IPAR2,IPAR3,IPAR4,IPAR5,IPAR6
     4,IFLAG,NS,NE,RMM(10),FRQ(10),ZETA(10)
      EXTERNAL HDR8,DTAD0,NMAX
      DATA ICMMD/2HD ,2HV ,2H% ,2HEX,2H: ,
     12HM ,2H_ ,2HRO,2HA-,2HAM,
     22HCH,2HSP,2HX(,
     32HX),2HCV,2H( ,2HB ,2HL ,
     42HW ,2HI ,2HK ,2HA+,2H/L,
     52HX /
C*************************************************************************
C        UNIVERSITY OF CINCINNATI/LEUVEN MODAL ANALYSIS PROGRAM
C
C        SET-UP OR INITIALIZATION PROGRAM (KEYBOARD ENTRIES)
C*************************************************************************
      IBELL=7B
      IPAGE=15414B
      CALL SETAD(HDR8,IH,-8,0)
      CALL SETAD(HDR8,RH(1),67,0)
      ICOMM=0
      IBS=1024
      CALL KYBD(2HBS,IBS,0)
      CALL GETI(NMAX,IBLM)
      ION=IBLM-1
      ICM=ION-1
      IBM=2
      I=ION*IBS+270
      CALL SETAD(DTAD0,IPTCM,I,-1)
      CALL RWCOM(0)
      IF(IFLAG.EQ.1)GO TO 1130
      IF(ICOMM.EQ.12345)GO TO 1000
C
C         THE FOLLOWING VARIABLES ARE INITIALIZED ONLY THE FIRST TIME
C
      DO 600 I=1,IBLM
      J=I-1
```

```
      CALL KYBD(2HCL,J)
  600 CONTINUE
      ICON=1
      NM=0
      NUMPT=1
      FSHFT=0.0
      NPD=2
      NMP=0
      NCOM=0
      IIBS=1024
      IP=1
      MDVA=0
      MANRE=0
      BETA=0.0
      MCF=0
      IBLS=1
      DO 800 I=1,3
      DO 800 J=1,10
      XXX(I,J)=0.0
      IX(1,J)=1
      IX(2,J)=2
      IX(3,J)=3
      IC(J)=1
      XR(I)=0.0
      IB(J)=0
      NCN(J)=0
      FRQ(J)=0.0
      ZETA(J)=0.0
      DO 800 K=1,2
      XXA(K,I)=0.0
      YYA(K,I)=0.0
  800 CONTINUE
C
C        SET UP DISPLAY VIEWING DEFAULT POSITION AS 1 1 1
C
      A(1,1)=0.70711
      A(1,2)=0.0
      A(1,3)=-0.70711
      A(2,1)=-0.408248
      A(2,2)=0.816497
      A(2,3)=-0.408248
      O(1)=0.
      O(2)=0.
      O(3)=0.
      DO 801 I=1,5
  801 IT(I)=2H
      DO 802  I=1,3
  802 ID(I)=2H
C**********************************************************************
C       START OF MONITOR
C**********************************************************************
  998 CONTINUE
      WRITE(1,997)IPAGE
  997 FORMAT(A2)
      WRITE(1,999)
  999 FORMAT(/,"UNIVERSITY OF CINCINNATI/LEUVEN MODAL ANALYSIS SYSTEM",/,
     115X,"VERSION:  NOVEMBER      1979")
 1000 WRITE(1,1010)IBELL
 1010 FORMAT("*",A2)
      I=ISWR(177677B,0,0)
```

```
      IPAR1=-9999
      IPAR2=-9999
      IPAR3=-9999
      IPAR4=-9999
      IPAR5=-9999
      IPAR6=-9999
 1020 DO 1030 I=1,36
 1030 LINE(I)=2H,,
 1040 CALL TTYIN(LINE)
 1042 CALL TEST(1,IST,LOG)
      IF(IST.LT.0)GO TO 1042
      CALL CODE
      READ(LINE,1120)IL
 1120 FORMAT(A2)
      CALL CODE
      READ(LINE1,*)IPAR1,IPAR2,IPAR3,IPAR4,IPAR5,IPAR6
C*********************************************************************
C       MONITOR COMMAND TABLE
C*********************************************************************
 1130 IFLAG=0
      CALL RWCOM(1)
      IF(IL.EQ.2H##)GO TO 1000
      NCMMD=24
      DO 1138  I=1,NCMMD
      IF(IL.EQ.ICMMD(I))GO TO 1144
 1138 CONTINUE
 1139 WRITE(1,1140)IBELL
 1140 FORMAT(/,"ERROR-ILLEGAL COMMAND",A2)
      GO TO 1000
 1144 IF(I.GT.10)GO TO 1146
      GO TO (9004,9004,9004,9004,9004,9004,9004,9004,9004,9004),I
 1146 I=I-10
      IF(I.GT.10)GO TO 1148
      GO TO (9004,9004,6000,6500,9004,9995,1100,1100,9002,1145),I
 1148 I=I-10
      GO TO (1145,9003,9008,9011),I
 1100 CONTINUE
      IF(IPAR1.EQ.37)GO TO 9005
      IF(IPAR1.EQ.10)GO TO 9006
      IF(IPAR1.EQ.6)GO TO 9007
      GO TO 1139
 1145 IF(IPAR1.EQ.-9999)IPAR1=0
      IF(IPAR1.EQ.0) GO TO 1152
      IF(IPAR1.EQ.1) GO TO 1260
      IF(IPAR1.EQ.2) GO TO 1400
      IF(IPAR1.EQ.3) GO TO 1460
      IF(IPAR1.EQ.4) GO TO 3000
      IF(IPAR1.EQ.5) GO TO 1660
      WRITE(1,1140)
      GO TO 1000
C***************************************************************
C         COMMAND KYBD 0   TEST ID AND SET-UP
C***************************************************************
 1152 DO 1153  I=1,5
 1153 IT(I)=2H
      WRITE(1,1154)IPAGE,IBELL
 1154 FORMAT(A2,/,"ENTER TEST ID-10 CHARACTERS",A2)
      READ(1,1156)(IT(JJJ),JJJ=1,5)
 1156 FORMAT(5A2)
      WRITE(1,1235)(IT(JJJ),JJJ=1,5)
```

```
      CALL RWCOM(1)
      WRITE(1,1158)IBELL
 1158 FORMAT(/,"ENTER DATE - 6 DIGITS(XXXXXX)",A2)
      READ(1,1157)ID(1),ID(2),ID(3)
 1157 FORMAT(3A2)
      WRITE(1,1159)IBELL
 1159 FORMAT(/,"ENTER NUMBER OF TEST POINTS",A2)
 1161 READ(1,*)IP
      IF(IP.GT.250) WRITE(1,1180)
      IF(IP.GT.250)GO TO 1161
      IF(NUMPT.GT.IP)NUMPT=IP
C
C         ALLOW TWO BLOCKS FOR COMMON AND DATA POINTS
C             AND TWO BLOCKS FOR DISPLAY
C
      XP=3.0*(FLOAT(IP))
      IBLS=IBLM-4
      Z1=FLOAT(IBLS*IBS)/XP
      NM=IFIX(Z1)
      IF(NM.GT.10)NM=10
      MANRE=NM
      WRITE(1,1160)NM
 1160 FORMAT(/,"ALLOWABLE NUMBER OF MODES STORED PER SESSION: ",I3)
 1180 FORMAT(/,"ERROR-NUMBER OF POINTS EXCEEDS 250")
 1190 CONTINUE
 1197 WRITE(1,1200)IBELL
 1200 FORMAT(/,"ENTER OPTION TO INITIALIZE THE DATA SPACE",
     1/,5X,"0)    CLEAR ONLY THE EXISTING MODAL COEFFICIENTS",
     2/,5X,"1)    CLEAR ALL EXISTING SET-UP FROM PREVIOUS TESTS",
     3/,5X,"          (GEOMETRY,CONNECTIVITY,MODAL COEFFICIENTS,ETC.)",
     4/,5X,"2)    RETURN TO MONITOR",A2,/)
      ICOMM=12345
      READ(1,*)IZ1
      IF(IZ1.EQ.0)GO TO 1210
      IF(IZ1.EQ.1)GO TO 1201
      IF(IZ1.EQ.2)GO TO 1000
      GO TO 1197
 1201 DO 1188 J=1,3
      DO 1188 I=1,10
      XXX(J,I)=0.0
      IX(J,I)=0
 1188 IC(I)=1
      NUMPT=1
      ICON=0
      NCOM=1
 1210 CALL GETQ(0,INQ)
      INQ(2)=176500B
      INQ(3)=77777B
      RMAX=0.
      IF(IZ1.EQ.0) IZ2=ION-2
      IF(IZ1.EQ.1) IZ2=ION
      DO 1220 I=IBM,IZ2
      CALL KYBD(2HCL,I)
 1220 CALL PUTQ(I,INQ)
      DO 1225 I=1,10
 1225 RMM(I)=0.0
      CALL RWCOM(1)
      GO TO 1000
 1235 FORMAT(/,"TEST ID IS",23X,5A2)
C***********************************************************************
```

```
C       COMMAND KYBD 1     COMPONENT DESCRIPTION
C**********************************************************************
 1260 WRITE(1,1270)IPAGE,IBELL
 1270 FORMAT(A2,/,"ENTER: COMPONENT NUMBER, X, Y, Z, IX, IY, IZ, IC",
     1//,5X,"IX,IY,IZ ARE THE NUMBERS OF THE TRANSDUCERS(1,2,3)",
     2/,5X,"IN THE GLOBAL X,Y,Z DIRECTIONS",A2,//)
 1275 DO 1277 I=1,36
 1277 LINE(I)=2H,,
 1280 CALL TTYIN(LINE)
 1290 CALL TEST(1,IST,LOG)
      IF(IST.LT.0)GO TO 1290
      CALL CODE
 1300 READ(LINE,*) I
      IF((I.LT.0).OR.(I.GT.10))GO TO 1305
      IF(I.EQ.0)ICOMM=12345
      IF(I.EQ.0) GO TO 1000
      IF(I.GT.NCOM)NCOM=I
      GO TO 1307
 1305 WRITE(1,1306)
 1306 FORMAT(/,"ERROR-INVALID COMPONENT NUMBER")
      GO TO 1275
 1307 CONTINUE
      CALL CODE
      READ(LINE1,*)XXX(1,I),XXX(2,I),XXX(3,I),
     1IX(1,I),IX(2,I),IX(3,I),IC(I)
      CALL RWCOM(1)
      GO TO 1275
C**********************************************************************
C       COMMAND KYBD 2     POINT NUMBER SET-UP
C**********************************************************************
 1400 WRITE(1,1410)IPAGE,IBELL
 1410 FORMAT(A2,/,"ENTER: POINT NUMBER, X,Y,Z COORDINATES, "
     1"COMPONENT NUMBER",A2)
C
C         PHOTOREAD OPTION - COORDINATES
C
      CALL IOSW(NU,1)
      IF(NU.EQ.5) PAUSE 1
 1420 READ(NU,*)I,Z1,Z2,Z3,IZ5
      IF(I.GT.IP) GO TO 1425
      IF(I.EQ.0)ICOMM=12345
      IF(I.EQ.0) GO TO 1000
      IF(I.LT.0)GO TO 1425
      IF(I.GT.NUMPT)NUMPT=I
      CALL RWCOR(I,Z1,Z2,Z3,ICM,0)
      IPTCM(I)=IZ5
      CALL RWCOM(1)
      GO TO 1420
 1425 WRITE(1,1427)
 1427 FORMAT(/,"ERROR-INVALID POINT NUMBER")
      GO TO 1420
C**********************************************************************
C       COMMAND KYBD 3     CONNECTIVITY SET-UP
C**********************************************************************
 1460 WRITE(1,1470)
 1470 FORMAT(/,"CONNECTIVITY MONITOR")
 1480 WRITE(1,1485)IBELL
 1485 FORMAT("*C",A2)
      IPAR1=-9999
      IPAR2=-9999
```

```
      CALL IPUT(IL,IPAR1,IPAR2,IPAR3,IPAR4)
 1490 IF(IL.EQ.2HK ) GO TO 1510
      IF(IL.EQ.2HW ) GO TO 1530
      IF(IL.EQ.2H/I) GO TO 1570
      IF(IL.EQ.2H/D) GO TO 1610
      IF(IL.EQ.2HR ) GO TO 1640
      IF(IL.EQ.2H# ) GO TO 1500
      IF(IL.EQ.2H< ) GO TO 1655
      IF(IL.EQ.2H/R) GO TO 1656
      WRITE(1,1140)
      GO TO 1480
C
C         COUNTER COMMAND - CONNECTIVITY
C
 1500 ICON=IPAR1
      GO TO 1480
C
C         KEYBOARD COMMAND - CONNECTIVITY
C
 1510 IZ2=-9999
      READ(1,*)IZ1,IZ2
      IF(IZ1.EQ.0)ICOMM=12345
      IF(IZ1.EQ.0) GO TO 1480
      IF((IZ2.LE.0).AND.(IZ2.GT.-9998)) GO TO 1480
      IF((IZ1.LT.0).AND.(IZ2.NE.-9999)) GO TO 1515
      GO TO 1516
 1515 IZ4=IABS(IZ1)
      IF(ICON.GT.500)WRITE(1,1535)
      IF(ICON.GT.500)GO TO 1480
 1535 FORMAT(/,"ERROR-MAXIMUM NUMBER OF DISPLAY VECTORS EXCEEDED")
      ICON=ICON+1
      CALL RWCON(ICON,IZ1,ION,0)
      INC=1
      IF(IZ4.GT.IZ2)INC=-1
      IZ1=IZ4+INC
 1516 IF(IZ2.EQ.-9999)IZ2=IZ1
      IF(IZ2.LT.IZ1) GO TO 1521
C
C         INCREMENT POINT NUMBERS
C
      DO 1520 I=IZ1,IZ2
      IF(ICON.GT.500)WRITE(1,1535)
      IF(ICON.GT.500)GO TO 1480
      ICON=ICON+1
 1520 CALL RWCON(ICON,I,ION,0)
      CALL RWCOM(1)
      GO TO 1510
C
C         DECREMENT POINT NUMBERS
C
 1521 IZ4=IZ1+1
      IZ5=IZ1-IZ2+1
      DO 1522 I=1,IZ5
      IZ4=IZ4-1
      IF(ICON.GT.500)WRITE(1,1535)
      IF(ICON.GT.500)GO TO 1480
      ICON=ICON+1
 1522 CALL RWCON(ICON,IZ4,ION,0)
      CALL RWCOM(1)
      GO TO 1510
```

```
C
C          PRINT COMMAND - CONNECTIVITY
C
  1530 IF(IPAR1.NE.-9999) GO TO 1540
       IPAR1=1
       IPAR2=ICON
  1540 NU=1
       IF(IPAR1.LT.1)GO TO 1000
       IF(IPAR2.EQ.-9999)IPAR2=IPAR1
       IF(IPAR2.LT.1)GO TO 1000
       DO 1550 I=IPAR1,IPAR2
       IF(ISSW(14).LT.0)GO TO 1562
       CALL RWCON(I,IZ1,ION,1)
  1550 WRITE(NU,1560)I,IZ1
  1560 FORMAT(2I6)
  1562 CONTINUE
       GO TO 1480
C
C          INSERT 'AFTER' COMMAND  CONNECTIVITY
C
  1570 IZ1=IPAR1+1
  1580 READ(1,*)IZ2
       IF(IZ2.EQ.0) GO TO 1480
       IF(ICON.GT.500)WRITE(1,1535)
       IF(ICON.GT.500)GO TO 1480
       ICON=ICON+1
       DO 1590 I=1,ICON
       IZ4=ICON-I
       IZ5=IZ4+1
       IF(IZ4.LT.IZ1) GO TO 1600
       CALL RWCON(IZ4,IZ3,ION,1)
  1590 CALL RWCON(IZ5,IZ3,ION,0)
  1600 CALL RWCON(IZ1,IZ2,ION,0)
       IZ1=IZ1+1
       GO TO 1580
C
C          DELETE COMMAND - CONNECTIVITY
C
  1610 IF(IPAR1.EQ.-9999)GO TO 1485
       IF(IPAR2.EQ.-9999)IPAR2=IPAR1
       IZ1=IPAR2-IPAR1+1
       DO 1620 I=1,ICON
       IZ2=IPAR1+I-1
       IZ3=IPAR2+I
       IF(IZ3.GT.ICON) GO TO 1630
       CALL RWCON(IZ3,IZ4,ION,1)
  1620 CALL RWCON(IZ2,IZ4,ION,0)
  1630 ICON=ICON-IZ1
       GO TO 1480
C
C         PHOTOREAD OPTION - CONNECTIVITY
C
  1640 CONTINUE
       ICON=0
       CALL IOSW(NU,1)
       IF(NU.NE.8)NU=5
       READ (NU,*) IZ1,IZ2
       DO 1650 I=IZ1,IZ2
       READ(NU,*)IZ3,IZ4
       IF(IZ4.EQ.0)GO TO 1480
```

```
      IF(ICON.GT.500)WRITE(1,1535)
      IF(ICON.GT.500)GO TO 1480
      ICON=ICON+1
 1650 CALL RWCON(IZ3,IZ4,ION,0)
      GO TO 1480
 1655 CONTINUE
      ICOMM=12345
      CALL RWCOM(1)
      GO TO 1000
C
C         REPLACE COMMAND - CONNECTIVITY
C
 1656 CONTINUE
      IZ1=IPAR1
      IF(IZ1.GT.ICON)WRITE(1,1658)
 1658 FORMAT(/,"ERROR-CONNECTIVITY LINE NUMBER TOO LARGE",//)
      IF(IZ1.GT.ICON)GO TO 1480
 1657 READ(1,*)IZ2
      IF(IZ2.EQ.0)GO TO 1480
      CALL RWCON(IZ1,IZ2,ION,0)
      IZ1=IZ1+1
      GO TO 1657
C***********************************************************************
C       COMMAND KYBD 4     FREQUENCIES AND DAMPING
C***********************************************************************
 3000 CONTINUE
      WRITE(1,3002)IPAGE,IBELL
 3002 FORMAT(A2,/,"ENTER RECORD NUMBER OF TYPICAL DATA",A2)
      READ(1,*)IREC
      CALL KYBD(2HMS,31,IREC)
      CALL KYBD(2HMS,11)
      FSHFT=RH(1)
      DF=RH(2)
C
C         MCF = 6 MEANS THAT FREQ/DAMP DATA HAS BEEN MANUALLY ENTERED
C
      MCF=6
      WRITE(1,3005)IBELL
 3005 FORMAT(/,"ENTER: MODE NUMBER,FREQUENCY,ZETA(%)",/
     1,"TERMINATE WITH MAXIMUM MODE,ZERO",A2,//)
 3010 CONTINUE
      READ(1,*)IMODE,F,Z
      IF(IMODE.EQ.0)GO TO 1000
      IF(F.EQ.0.0)MANRE=IMODE
      IF(F.EQ.0.0)GO TO 1000
      IF((IMODE.LT.1).OR.(IMODE.GT.10))GO TO 3400
      FRQ(IMODE)=F
      ZETA(IMODE)=Z
      IB(IMODE)=F*Z/(DF*SQRT(10000.0-Z**2))
      NCN(IMODE)=F/DF-FSHFT/DF+1
      GO TO 3010
 3400 CONTINUE
      WRITE(1,3405)IBELL
 3405 FORMAT(/,"ERROR-INVALID MODE NUMBER",A2,/)
      GO TO 3010
C***********************************************************************
C       COMMAND KYBD 5     MODAL COEFFICIENTS
C***********************************************************************
 1660 WRITE(1,1670)IPAGE,IBELL
 1670 F RMAT(A2  ,"ENTER: MODE NUMBER, POINT NUMBER, X,Y,Z "
```

```
      1"DEFORMATIONS, X,Y,Z PHASE ANGLES",
      2/,5X,"(DEFORMATIONS = + OR - MAGNITUDE)",
      3/,5X,"(PHASE ANGLES = 0 TO 180 DEGREES)",/,A2)
C
C        PHOTOREAD OPTION - MODAL COEFFICIENTS
C
       CALL IOSW(NU,1)
       IF(NU.EQ.5) PAUSE 2
 1680  READ(NU,*)M,I,Z1,Z2,Z3,LO1,LO2,LO3
       IF(M.LE.0)GO TO 1000
       RMAX=RMM(M)
       CALL RWCMC(1,Z1,LO1,M,I,IP,IBM,RMAX,0)
       CALL RWCMC(2,Z2,LO2,M,I,IP,IBM,RMAX,0)
       CALL RWCMC(3,Z3,LO3,M,I,IP,IBM,RMAX,0)
       RMM(M)=RMAX
       GO TO 1680
C
C       STORE AND READ SET-UP AND MODAL DATA TO AND FROM DISC
C
C        READ
C
 6000  CALL KYBD(2HMS,35,1)
       CALL KYBD(2HMS,25)
       IF(IPAR1.EQ.-9999)GO TO 9011
       IF((IPAR1.GE.0).AND.(IPAR1.LE.800)) CALL KYBD(2HMS,31,IPAR1)
       IF((IPAR1.LT.0).OR.(IPAR1.GT.800))GO TO 6800
       CALL KYBD(2HMS,11,0)
       CALL KYBD(2HMS,31,-1,1)
       CALL RWCOM(-1)
       IF(ICOMM.NE.12345)GO TO 6800
       CALL KYBD(2HMS,11,ION)
       CALL RWCOM(0)
       IF(ICOMM.NE.12345)GO TO 6800
       NMP=0
       IRJ=ICM
       CALL KYBD(2HMS,11,IRJ)
       IRJ=IRJ-1
 6100  DO 6200 I=IBM,IRJ
 6200  CALL KYBD(2HMS,11,I)
       CALL KYBD(2HMS,35,1)
       CALL KYBD(2HMS,15)
       ICOMM=12345
       WRITE(1,1235)(IT(I),I=1,5)
       GO TO 1000
C
C        STORE
C
 6500  CALL KYBD(2HMS,35,1)
       CALL KYBD(2HMS,25)
       IF(IPAR1.EQ.-9999)GO TO 9011
       IF((IPAR1.GE.0).AND.(IPAR1.LE.800))CALL KYBD(2HMS,31,IPAR1)
       IF((IPAR1.LT.0).OR.(IPAR1.GT.800))GO TO 6800
       IL=2H**
       CALL RWCOM(1)
       IH(6)=52525B
       IH(9)=10
       IH(10)=IT(1)
       IH(11)=IT(2)
       IH(12)=IT(3)
       IH(13)=IT(4)
```

```
      IH(14)=IT(5)
      IH(34)=2H71
      CALL KYBD(2HMS,21,ION)
      CALL KYBD(2HMS,21,ICM)
      IH(34)=2H72
      IRJ=ICM-1
      IPAR1=IPAR1+2
      DO 6700 I=IBM,IRJ
      IPAR1=IPAR1+1
 6700 CALL KYBD(2HMS,21,I)
      WRITE(1,6701)IPAR1
 6701 FORMAT(/,"NEXT DATA RECORD IS ",I4)
      CALL KYBD(2HMS,35,1)
      CALL KYBD(2HMS,15)
      GO TO 1000
 6800 WRITE(1,6801)
 6801 FORMAT(/,"ERROR-INVALID DATA RECORD")
      NMP=0
      ICOMM=12345
      GO TO 1000
C***********************************************************************
C          EXIT TO OTHER OVERLAYS
C***********************************************************************
 9002 I=2
      GO TO 9900
 9003 I=3
      GO TO 9900
 9004 I=4
      GO TO 9900
 9005 I=5
      GO TO 9900
 9006 I=6
      GO TO 9900
 9007 I=7
      GO TO 9900
 9008 I=8
      GO TO 9900
 9011 I=11
      GO TO 9900
 9900 CONTINUE
      IFLAG=1
      CALL RWCOM(1)
      CALL KYBD(2HMS,38,I)
      CALL OVLD(9)
 9995 CONTINUE
      IL=2H**
      IF(ICOMM.EQ.12345)CALL RWCOM(1)
      CALL KYBD(2HBS,IBS,0)
      RETURN
      END
      END$
```

```
$Y902  T=00004 IS ON CR00103 USING 00082 BLKS R=0702

FTN4
      SUBROUTINE Y0009(INTOT,IPAR)
C
C         THIS PROGRAM IS STORED UNDER $Y902
C
C*************************************************************************
C
C        PROGRAMMER:  R.J.ALLEMANG
C                     MAIL LOCATION # 72
C                     UNIVERSITY OF CINCINNATI
C                     CINCINNATI, OHIO  45221
C                     513-475-6670
C
C        REVISION DATE:  DEC 17,1979
C
C*************************************************************************
      DIMENSION IPAR(6),LINE(36),LINE1(35),IZ(10),INQ(6)
     1,IDIV(1),ICMMD(24),IH(1),IX1(1),IY1(1),IDX(1),IDY(1)
     2,IC1(1),IPTCM(1)
      EQUIVALENCE (LINE(2),LINE1)
      COMMON ICOMM,MANRE,MDVA,BETA,IBLS,IT(5),ID(3),IP,NUMPT
     1,NM,ICON,NCOM,XXX(3,10),IX(3,10),IC(10),NMP,XR(3),A(2,3)
     2,O(3),IB(10),NCN(10),SF(2),XXA(2,3),YYA(2,3)
     3,FSHFT,DF,MCF,IZR,IL,IPAR1,IPAR2,IPAR3,IPAR4,IPAR5,IPAR6
     4,IFLAG,NS,NE,RMM(10),FRQ(10),ZETA(10)
      EXTERNAL HDR8,DTAD0,NMAX
      DATA ICMMD/2HD ,2HV ,2H% ,2HEX,2H: ,
     12HM ,2H_ ,2HRO,2HA-,2HAM,
     22HCH,2HSP,2HX<,
     32HX>,2HCV,2H< ,2HB ,2HL ,
     42HW ,2HI ,2HK ,2HA+,2H/L,
     52HX /
C*************************************************************************
C        UNIVERSITY OF CINCINNATI/LEUVEN MODAL ANALYSIS PROGRAM
C
C        OUTPUT PROGRAM (PRINT COMMAND)
C*************************************************************************
      IBELL=7B
      IPAGE=15414B
      CALL SETAD(HDR8,IH,-8,0)
      ICOMM=0
      IBS=1024
      CALL KYBD(2HBS,IBS,0)
      CALL GETI(NMAX,IBLM)
      ION=IBLM-1
      ICM=ION-1
      IBM=2
      I=ION*IBS+270
      CALL SETAD(DTAD0,IPTCM,I,-1)
      CALL RWCOM(0)
      IF(ICOMM.EQ.12345)GO TO 900
      CALL KYBD(2HMS,38,-2,1)
      CALL OVLD(9)
 900  CONTINUE
      IF(IFLAG.EQ.1)GO TO 1130
C*************************************************************************
C       START OF MONITOR
C*************************************************************************
```

```
 1000 WRITE(1,1010)IBELL
 1010 FORMAT("*",A2)
      I=ISWR(177677B,0,0)
      IPAR1=-9999
      IPAR2=-9999
      IPAR3=-9999
      IPAR4=-9999
      IPAR5=-9999
      IPAR6=-9999
 1020 DO 1030 I=1,36
 1030 LINE(I)=2H,,
 1040 CALL TTYIN(LINE)
 1042 CALL TEST(1,IST,LOG)
      IF(IST.LT.0)GO TO 1042
      CALL CODE
      READ(LINE,1120)IL
 1120 FORMAT(A2)
      CALL CODE
      READ(LINE1,*)IPAR1,IPAR2,IPAR3,IPAR4,IPAR5,IPAR6
C***********************************************************************
C       MONITOR COMMAND TABLE
C***********************************************************************
 1130 IFLAG=0
      CALL RWCOM(1)
      IF(IL.EQ.2H**)GO TO 1000
      NCMMD=24
      DO 1138  I=1,NCMMD
      IF(IL.EQ.ICMMD(I))GO TO 1144
 1138 CONTINUE
 1139 WRITE(1,1140)
 1140 FORMAT(/,"ERROR-ILLEGAL COMMAND")
      GO TO 1000
 1144 IF(I.GT.10)GO TO 1146
      GO TO (9004,9004,9004,9004,9004,9004,9004,9004,9004,9004),I
 1146 I=I-10
      IF(I.GT.10)GO TO 1148
      GO TO (9004,9004,6000,6500,9004,9995,1100,1100,1142,9001),I
 1148 I=I-10
      GO TO (9001,9003,9008,9011),I
 1100 CONTINUE
      IF(IPAR1.EQ.37)GO TO 9005
      IF(IPAR1.EQ.10)GO TO 9006
      IF(IPAR1.EQ.6)GO TO 9007
      GO TO 1139
C
C       PRINTER COMMAND TABLE
C
C         PRINT COMMAND DEFAULTS TO SET-UP FILE
C
 1142 IF(IPAR1.EQ.-9999)IPAR1=0
      IF(IPAR1.EQ.0)GO TO 1250
      IF(IPAR1.EQ.1) GO TO 1310
      IF(IPAR1.EQ.2) GO TO 1430
      IF(IPAR1.EQ.3) GO TO 1525
      IF(IPAR1.EQ.4) GO TO 1690
      IF(IPAR1.EQ.5) GO TO 1695
      WRITE(1,1140)
      GO TO 1000
C***********************************************************************
C       COMMAND PRINT 0    TEST ID AND SET-UP
```

```
C*********************************************************************
C
C         PRINT-OUT FOR KYBD 0
C
 1250 CONTINUE
      CALL IOSW(NU,0)
      WRITE(NU,1235)(IT(JJJ),JJJ=1,5)
 1235 FORMAT(/,"TEST ID IS",23X,5A2)
      WRITE(NU,1251)ID(1),ID(2),ID(3)
 1251 FORMAT("DATE IS",26X,3( A2,1X),/)
      WRITE(NU,1252)IP,NM
 1252 FORMAT("NUMBER OF POINTS IS",20X,I3,/,
     1"NUMBER OF MODES IS",22X,I2)
      GO TO 1000
C*********************************************************************
C       COMMAND PRINT 1    COMPONENT DESCRIPTION
C*********************************************************************
C
C         PRINT COMMAND - COMPONENTS
C
 1310 IZ1=IPAR2
      IZ2=IPAR3
      IF(IPAR2.EQ.-9999) IZ1=1
      IF(IPAR2.EQ.-9999) IZ2=NCOM
      IF((IPAR2.NE.-9999).AND.(IPAR3.EQ.-9999))IZ2=IZ1
      IF((IZ1.LE.0).OR.(IZ1.GT.NCOM))IZ1=1
      IF((IZ2.LE.0).OR.(IZ2.GT.NCOM))IZ2=NCOM
      CALL IOSW(NU,0)
      DO 1320 I=IZ1,IZ2
 1320 WRITE(NU,1330)I,XXX(1,I),XXX(2,I),XXX(3,I),IX(1,I),IX(2,I)
     1,IX(3,I),IC(I)
 1330 FORMAT(2X,I2,2X,3F11.4,4I6)
      GO TO 1000
C*********************************************************************
C       COMMAND PRINT 2    POINT NUMBER SET-UP
C*********************************************************************
C
C         PUNCH/PRINT   OPTION - COORDINATES
C
 1430 CONTINUE
      CALL IOSW(NU,0)
      IR=0
      IZ1=IPAR2
      IZ2=IPAR3
      IF(IPAR2.EQ.-9999)IZ2=NUMPT
      IF(IPAR2.EQ.-9999)IZ1=1
      IF((IPAR2.NE.-9999).AND.(IPAR3.EQ.-9999))IZ2=IPAR2
      IF((IZ1.LE.0).OR.(IZ1.GT.IP))IZ1=1
      IF((IZ2.LE.0).OR.(IZ2.GT.IP))IZ2=NUMPT
      IF((NU.EQ.1).OR.(NU.EQ.6))WRITE(NU,1432)(IT(I),I=1,5)
 1432 FORMAT("",/,"TEST I.D.     ",5A2,
     $2/,"POINT",10X,"X",11X,"Y",11X,"Z",5X,"COMPONENT",/)
      DO 1440 I=IZ1,IZ2
      IF(ISSW(14).LT.0)GO TO 1000
      CALL RWCOR(I,Z1,Z2,Z3,ICM,1)
      IZ5=IPTCM(I)
      IF(NU.EQ.8)GO TO 1434
      IF(NU.EQ.4)GO TO 1434
      IR=IR+1
      IF(IR.GT.54)WRITE(NU,1432)(IT(IJ),IJ=1,5)
```

```
      IF(IR.GT.54)IR=0
 1434 CONTINUE
 1440 WRITE(NU,1450)I,Z1,Z2,Z3,IZ5
      I=0
      IF((NU.NE.4).OR.(NU.NE.8))GO TO 1000
      WRITE(NU,1450)I,IZ1,Z2,Z3,IZ5
 1450 FORMAT(I5,1X,3(2X,F10.2),1X,I5)
      IF(NU.NE.8)GO TO 1000
      END FILE NU
      GO TO 1000
C**********************************************************************
C       COMMAND PRINT 3    CONNECTIVITY SET-UP
C**********************************************************************
C
C          PRINT COMMAND - CONNECTIVITY
C
 1525 IPAR1=IPAR2
      IPAR2=IPAR3
 1530 IF(IPAR1.NE.-9999) GO TO 1540
      IPAR1=1
      IPAR2=ICON
 1540 CALL IOSW(NU,0)
C
C          PUNCH OPTION  CONNECTIVITY
C
      IF(IPAR1.LT.1)GO TO 1139
      IF(IPAR2.EQ.-9999)IPAR2=IPAR1
      IF(IPAR2.LT.1)GO TO 1139
      IF((NU.EQ.1).OR.(NU.EQ.6))GO TO 1545
      WRITE(NU,1560)IPAR1,IPAR2
 1545 CONTINUE
      DO 1550 I=IPAR1,IPAR2
      IF(ISSW(14).LT.0)GO TO 1562
      CALL RWCON(I,IZ1,ION,1)
 1550 WRITE(NU,1560)I,IZ1
 1560 FORMAT(2I6)
      IF(NU.NE.8)GO TO 1562
      END FILE NU
 1562 CONTINUE
      GO TO 1000
C**********************************************************************
C       COMMAND PRINT 4    FREQUENCIES AND DAMPING
C**********************************************************************
 1690 CONTINUE
      CALL IOSW(NU,0)
      IF((NU.EQ.1).OR.(NU.EQ.6))WRITE(NU,2000)
 2000 FORMAT(/,"MODE  CHANNEL  BANDWIDTH  FREQUENCY  ZETA(%)"
     1,"   METHOD    MODE",/)
      DO 1692 I=1,MANRE
      J=MCF
      IF(I.GT.NM)J=0
      WRITE(NU,1693)I,NCN(I),IB(I),FRQ(I),ZETA(I),J,I
      IF(I.EQ.NM)WRITE(NU,1696)
 1696 FORMAT(" ")
 1692 CONTINUE
 1693 FORMAT(I3,3X,I5,6X,I3,4X,F10.3,2X,F10.7,4X,I3,4X,I3)
      IF(NU.NE.8)GO TO 1000
      END FILE NU
      GO TO 1000
C*********************************************************************
```

```
C        COMMAND PRINT 5    PRINT OF MODAL COEFFICIENTS
C**********************************************************************
 1695 CONTINUE
      IZ1=IPAR2
      IF(IZ1.GT.NM)IZ1=1
      I=IPAR3
      IZ2=IPAR4
      IF(I.LE.0)I=1
      IF(I.GT.IP)I=1
      IF(IZ2.LE.0)IZ2=NUMPT
      IF(IZ2.GT.IP)IZ2=NUMPT
C
C         PUNCH OPTION  MODAL COEFFICIENTS
C
      CALL IOSW(NU,0)
      IF((NU.EQ.1).OR.(NU.EQ.6))WRITE(NU,2002)
 2002 FORMAT(/,"MODE POINT           X,Y,Z DEFORMATIONS"
     1,"                X,Y,Z PHASE ANGLES",/)
      RMAX=RMM(IZ1)
      DO 1700 II=I,IZ2
      IF(ISSW(14).LT.0)GO TO 1000
      CALL RWCMC(1,Z1,LO1,IZ1,II,IP,IBM,RMAX,1)
      CALL RWCMC(2,Z2,LO2,IZ1,II,IP,IBM,RMAX,1)
      CALL RWCMC(3,Z3,LO3,IZ1,II,IP,IBM,RMAX,1)
C
C        THIS WRITE MUST BE THE SAME AS 1680
C
 1700 WRITE(NU,1710)IZ1,II,Z1,Z2,Z3,LO1,LO2,LO3
 1710 FORMAT(I2,I5,1X,3(2X,G12.3),3(2X,I4))
      IZ1=0
      II=0
      Z1=0.0
      Z2=0.0
      Z3=0.0
      LO1=0
      LO2=0
      LO3=0
      WRITE(NU,1710)IZ1,II,Z1,Z2,Z3,LO1,LO2,LO3
      IF(NU.NE.8)GO TO 1000
      END FILE NU
      GO TO 1000
C
C       STORE AND READ SET-UP AND MODAL DATA TO AND FROM DISC
C
C        READ
C
 6000 CALL KYBD(2HMS,35,1)
      CALL KYBD(2HMS,25)
      IF(IPAR1.EQ.-9999)GO TO 9011
      IF((IPAR1.GE.0).AND.(IPAR1.LE.800)) CALL KYBD(2HMS,31,IPAR1)
      IF((IPAR1.LT.0).OR.(IPAR1.GT.800))GO TO 6800
      CALL KYBD(2HMS,11,0)
      CALL KYBD(2HMS,31,-1,1)
      CALL RWCOM(-1)
      IF(ICOMM.NE.12345)GO TO 6800
      CALL KYBD(2HMS,11,ION)
      CALL RWCOM(0)
      IF(ICOMM.NE.12345)GO TO 6800
      NMP=0
      IRJ=ICM
```

```
      CALL KYBD(2HMS,11,IRJ)
      IRJ=IRJ-1
 6100 DO 6200 I=IBM,IRJ
 6200 CALL KYBD(2HMS,11,I)
      CALL KYBD(2HMS,35,1)
      CALL KYBD(2HMS,15)
      ICOMM=12345
      WRITE(1,1235)(IT(I),I=1,5)
      GO TO 1000
C
C        STORE
C
 6500 CALL KYBD(2HMS,35,1)
      CALL KYBD(2HMS,25)
      IF(IPAR1.EQ.-9999)GO TO 9011
      IF((IPAR1.GE.0).AND.(IPAR1.LE.800))CALL KYBD(2HMS,31,IPAR1)
      IF((IPAR1.LT.0).OR.(IPAR1.GT.800))GO TO 6800
      IL=2H##
      CALL RWCOM(1)
      IH(6)=52525B
      IH(9)=10
      IH(10)=IT(1)
      IH(11)=IT(2)
      IH(12)=IT(3)
      IH(13)=IT(4)
      IH(14)=IT(5)
      IH(34)=2H71
      CALL KYBD(2HMS,21,ION)
      CALL KYBD(2HMS,21,ICM)
      IH(34)=2H72
      IRJ=ICM-1
      IPAR1=IPAR1+2
      DO 6700 I=IBM,IRJ
      IPAR1=IPAR1+1
 6700 CALL KYBD(2HMS,21,I)
      WRITE(1,6701)IPAR1
 6701 FORMAT(/,"NEXT DATA RECORD IS ",I4)
      CALL KYBD(2HMS,35,1)
      CALL KYBD(2HMS,15)
      GO TO 1000
 6800 WRITE(1,6801)
 6801 FORMAT(/,"ERROR-INVALID DATA RECORD")
      NMP=0
      ICOMM=12345
      GO TO 1000
C*********************************************************************
C         EXIT TO OTHER OVERLAYS
C*********************************************************************
 9001 I=1
      GO TO 9900
 9003 I=3
      CO TO 9900
 9004 I=4
      GO TO 9900
 9005 I=5
      GO TO 9900
 9006 I=6
      GO TO 9900
 9007 I=7
      GO TO 9900
```

```
 9008 I=8
      GO TO 9900
 9011 I=11
      GO TO 9900
 9900 CONTINUE
      IFLAG=1
      CALL RWCOM(1)
      CALL KYBD(2HMS,38,I)
      CALL OVLD(9)
 9995 CONTINUE
      IL=2H##
      IF(ICOMM.EQ.12345)CALL RWCOM(1)
      CALL KYBD(2HBS,IBS,0)
      RETURN
      END
      END$
```

```
$Y903  T=00004 IS ON CR00103 USING 00063 BLKS R=0548

FTN4
      SUBROUTINE Y0009(INTOT,IPAR)
C
C         THIS PROGRAM IS STORED UNDER $Y903
C
C***********************************************************************
C
C        PROGRAMMER:  R.J.ALLEMANG
C                     MAIL LOCATION # 72
C                     UNIVERSITY OF CINCINNATI
C                     CINCINNATI, OHIO  45221
C                     513-475-6670
C
C        REVISION DATE:  DEC 17,1979
C
C***********************************************************************
      DIMENSION IPAR(6),LINE(36),LINE1(35),IZ(10),INQ(6)
     1,IDIV(1),ICMMD(24),IH(1),IX1(1),IY1(1),IDX(1),IDY(1)
     2,IC1(1),IPTCM(1),RH(1)
      EQUIVALENCE (LINE(2),LINE1)
      COMMON ICOMM,MANRE,MDVA,BETA,IBLS,IT(5),ID(3),IP,NUMPT
     1,NM,ICON,NCOM,XXX(3,10),IX(3,10),IC(10),NMP,XR(3),A(2,3)
     2,O(3),IB(10),NCN(10),SF(2),XXA(2,3),YYA(2,3)
     3,FSHFT,DF,MCF,IZR,IL,IPAR1,IPAR2,IPAR3,IPAR4,IPAR5,IPAR6
     4,IFLAG,NS,NE,RMM(10),FRQ(10),ZETA(10)
      EXTERNAL HDR8,DTAD0,NMAX
      DATA YMAX/0./
      DATA ICMMD/2HD ,2HV ,2H% ,2HEX,2H: ,
     12HM ,2H_ ,2HRO,2HA-,2HAM,
     22HCH,2HSP,2HX<,
     32HX>,2HCV,2H( ,2HB ,2HL ,
     42HW ,2HI ,2HK ,2HA+,2H/L,
     52HX /
C***********************************************************************
C         UNIVERSITY OF CINCINNATI/LEUVEN MODAL ANALYSIS PROGRAM
C
C         PARAMETER ESTIMATION SET-UP PROGRAM
C***********************************************************************
      IBELL=7B
      IPAGE=15414B
      ICOMM=12345
      IFLG2=7777
      IBS=1024
      CALL SETAD(HDR8,IH,-8,0)
      CALL SETAD(HDR8,RH(1),67,0)
      CALL KYBD(2HBS,IBS,0)
      CALL GETI(NMAX,IBLM)
      ION=IBLM-1
      ICM=ION-1
      IBM=2
      CALL RWCOM(0)
C
C         IF PROGRAM REQUIRES INITIALIZATION, LOAD Y 91
C
      IF(ICOMM.EQ.12345)GO TO 900
      CALL KYBD(2HMS,38,-3,1)
      CALL OVLD(9)
  900 CONTINUE
```

```
      IFLG4=0
      IF(IFLAG.EQ.1)GO TO 1130
      IF(IFLAG.EQ.96)GO TO 1900
      IF(IFLAG.EQ.97)GO TO 1000
      IF(ICOMM.NE.12345)GO TO 1000
C*************************************************************
C        START OF MONITOR
C*************************************************************
 1000 WRITE(1,1010)IBELL
 1010 FORMAT("*",A2)
      I=ISWR(177677B,0,0)
      IPAR1=-9999
      IPAR2=-9999
      IPAR3=-9999
      IPAR4=-9999
      IPAR5=-9999
      IPAR6=-9999
 1020 DO 1030 I=1,36
 1030 LINE(I)=2H,
 1040 CALL TTYIN(LINE)
 1042 CALL TEST(1,IST,LOG)
      IF(IST.LT.0)GO TO 1042
      CALL CODE
      READ(LINE,1120)IL
      IF(ICOMM.EQ.12345)GO TO 1115
 1115 CONTINUE
 1120 FORMAT(A2)
      CALL CODE
      READ(LINE1,*)IPAR1,IPAR2,IPAR3,IPAR4,IPAR5,IPAR6
C*************************************************************
C         MONITOR COMMAND TABLE
C*************************************************************
 1130 IFLAG=0
      CALL RWCOM(1)
      IF(IL.EQ.2H**)GO TO 1000
      NCMMD=24
      DO 1138 I=1,NCMMD
      IF(IL.EQ.ICMMD(I))GO TO 1144
 1138 CONTINUE
 1139 WRITE(1,1140)
 1140 FORMAT(/,"ERROR-ILLEGAL COMMAND")
      GO TO 1000
 1144 IF(I.GT.10)GO TO 1146
      GO TO (9004,9004,9004,9004,9004,9004,9004,9004,9004,9004),I
 1146 I=I-10
      IF(I.GT.10)GO TO 1148
      GO TO (9004,9004,6000,6500,9004,9995,1100,1100,9002,9001),I
 1148 I=I-10
      GO TO (9001,1400,9008,9011),I
 1100 CONTINUE
      IF(IPAR1.EQ.37)GO TO 9005
      IF(IPAR1.EQ.10)GO TO 9006
      IF(IPAR1.EQ.6)GO TO 9007
      GO TO 1139
C****************************************************
C        MODAL SET-UP   STARTING VALUES
C****************************************************
 1400 CONTINUE
      WRITE(1,1450)IPAGE,IBELL
      READ(1,*)IANS
```

```
 1450 FORMAT(A2,/,"ENTER OPTION TO BE USED",
     1" FOR FREQUENCIES AND DAMPING",
     2 /,"        1) MANUAL",
     3 /,"        2) CURSOR",
     4 /,"        3) LEAST SQUARES ESTIMATE",
     5 /,"        4) CURRENTLY SELECTED VALUES",
     6 /,"        5) RETURN TO MONITOR",A2,/)
      IF((IANS.LT.1).OR.(IANS.GT.5))GO TO 1400
      IF(IANS.EQ.5)GO TO 1000
      IF(IANS.EQ.4)GO TO 1900
      MCF=0
      DO 1460  I=1,10
      FRQ(I)=0.0
      ZETA(I)=0.0
      NCN(I)=0
      IB(I)=0
 1460 CONTINUE
      IFLG4=1
C
C       IFLG4=0       CURSER HAS ALREADY BEEN INITIALIZED
C       IFLG4=1       THIS IS THE FIRST TIME INTO CURSER
C
 1500 WRITE(1,1600)IBELL
 1600 FORMAT(A2,/,"INPUT DISC DATA RECORD OF TYPICAL TEST DATA:")
      READ(1,*)I
      IF((I.LT.0).OR.(I.GT.810))GO TO 1500
      CALL KYBD(2HMS,31,I)
      CALL KYBD(2HMS,11,0)
      IIBS=IH(5)
C
C       MAKING SURE ALL OF THE BLOCK WAS LOADED
C
      IF((IIBS.LE.2048).AND.(IIBS.GE.128))GO TO 1650
      WRITE(1,1651)
 1651 FORMAT(/,"ERROR-ILLEGAL BLOCK SIZE")
 1650 CONTINUE
      CALL KYBD(2HBS,IIBS,0)
      CALL KYBD(2HMS,31,I)
      CALL KYBD(2HMS,11,0)
      IZR=IH(36)
      IF(IH(4).NE.99)GO TO 1680
      WRITE(1,1670)IZR
 1670 FORMAT(/,"ZOOM RANGE OF THE DATA IS",2X,A2)
 1680 CONTINUE
      FSHFT=RH(1)
      DF=RH(2)
      IF(IANS.LT.3)GO TO 1700
C
C        LEAST SQUARES STARTING VALUE SET-UP
C
      WRITE(1,1665)IBELL
 1665 FORMAT(/,"ENTER OPTION FOR CHOICE OF STARTING CHANNEL:",A2
     1/,5X,"1) MANUAL",
     2/,5X,"2) CURSOR",/)
      READ(1,*)MMMM
      IF(MMMM.EQ.2)GO TO 1668
      WRITE(1,1669)IBELL
 1669 FORMAT(/,"ENTER CHANNEL NUMBER:",A2,/)
      READ(1,*)NS
      GO TO 1772
```

```
 1668 CONTINUE
      WRITE(1,1660)IBELL
 1660 FORMAT(/,"SET CURSOR ON STARTING CHANNEL:",A2,/)
      ITEMP=0
      CALL CURSE(0,ITEMP)
      IF(ITEMP.EQ.-9999)NS=0
      NS=IABS(ITEMP)
 1772 CONTINUE
      IF(NS.EQ.0)NS=1
      F=FLOAT(NS)*DF+FSHFT
 1688 WRITE(1,1691)IBELL
 1691 FORMAT(/,"ENTER NUMBER OF POINTS TO BE USED IN THE",
     1," PARAMETER ESTIMATION:",/,5X,"(64,128,256)",A2,/)
      READ(1,*)NE
      IF((NE.EQ.64).OR.(NE.EQ.128).OR.(NE.EQ.256))GO TO 1696
      GO TO 1688
 1696 CONTINUE
      M3=400
      IF(NE.EQ.64)M3=700
      IF(M3.EQ.256)M3=300
      NE=NS+NE
      DO 1695 MMMM=1,M3
 1695 CALL KDIS(0,NS,NE,4)
      WRITE(1,1692)F,NS,NE,IBELL
 1692 FORMAT(/"STARTING FREQUENCY",E14.5,
     1/,"CHANNEL ",I5," TO ",I5,
     2//,"ENTER 0 TO ACCEPT:",A2,/)
      READ(1,*)MMMM
      IF(MMMM.NE.0)GO TO 1400
      CALL KYBD(2HBS,IBS,0)
      GO TO 9009
C
C           MANUAL AND CURSOR STARTING VALUE SET-UP
C
 1700 CONTINUE
      WRITE(1,1730)IBELL
 1730 FORMAT(/,"ENTER MODE NUMBER AND BANDWIDTH:",A2)
 1740 READ(1,*)M,IBW
      IF(M.LT.0)GO TO 1500
      IF(M.EQ.0) GO TO 1800
      IF(M.GT.NM) WRITE(1,1760)
      IF(M.GT.NM) GO TO 1700
      IF(IANS.EQ.2)GO TO 1743
      WRITE(1,1742)IBELL
 1742 FORMAT(/,"ENTER CHANNEL NUMBER:",A2)
      READ(1,*)ITEMP
      GO TO 1746
 1743 CONTINUE
      IF(IFLG4.EQ.1)ITEMP=0
      IF(IFLG4.EQ.1)IFLG4=0
      CALL CURSE(0,ITEMP)
      IF(ITEMP.EQ.-9999)NCN(M)=0
      IF(ITEMP.EQ.-9999)GO TO 1000
 1746 NCN(M)=IABS(ITEMP)
      ITEMP=IABS(ITEMP)
      FRQ(M)=FLOAT(NCN(M))*DF+FSHFT
      WRITE(1,1750)NCN(M),FRQ(M)
 1750 FORMAT(I4,2X,F12.4)
 1760 FORMAT(/,"ERROR-VALUE GREATER THAN NUMBER OF MODES")
      IB(M)=IBW
```

```
      GO TO 1700
 1800 CONTINUE
      CALL KYBD(2HBS,IBS,0)
      CALL RWCOM(1)
C***********************************************************************
C        MODAL COEFFICIENT ACQUISITION        PARAMETER ESTIMATION
C***********************************************************************
 1900 CONTINUE
      WRITE(1,1905)IPAGE,IBELL
 1905 FORMAT(A2,/,"ENTER OPTION TO BE USED TO",
     1" DETERMINE MODAL COEFFICIENTS:"
     1,/,"        1) MAGNITUDE"
     2,/,"        2) IMAGINARY PART"
     3,/,"        3) REAL PART"
     4,/,"        4) KENNEDY-PANCU CIRCLE FIT"
     5,/,"        5) LEAST-SQUARES FREQUENCY DOMAIN"
     6,/,"        6) RETURN TO MONITOR",A2,/)
      READ(1,*)IANS
      IF((IANS.LT.1).OR.(IANS.GT.6))GO TO 1900
      IF(IANS.EQ.6)GO TO 1000
      WRITE(1,1906)IBELL
 1906 FORMAT(/,"ENTER 0 TO CLEAR CURRENT MODAL COEFFICIENTS",A2)
      READ(1,*)I
      IF(I.NE.0)GO TO 1909
      CALL KYBD(2HCL,0)
      CALL GETQ(0,INQ)
      INQ(2)=176500B
      INQ(3)=77777B
      DO 1907 I=IBM,ION-2
      CALL KYBD(2HCL,I)
 1907 CALL PUTQ(I,INQ)
      DO 1908 I=1,10
 1908 RMM(I)=0.0
      CALL RWCOM(1)
 1909 CONTINUE
      MCF=IANS
      IF(IANS.EQ.5)GO TO 9010
      ICUR=-9999
      WRITE(1,1910)IBELL
 1910 FORMAT(" SWITCH 15  ABORT POINT PRINT",
     1/," SWITCH 14  ABORT PARAMETER ESTIMATION",
     2/," SWITCH 13  ABORT AUTOMATIC CALIBRATION",
     3/," SWITCH 12  SKIP DIRECTIONAL COSINE CHECK",
     4/," SWITCH 11  ABORT NIXIE TUBE DISPLAY",
     5/," SWITCH 10  SUPPRESS SCALING QUESTION",
     5/," SWITCH  0  AUTOMATIC CIRCLE FIT",
     6//," ENTER RANGE OF DISC RECORDS FOR CURRENT TEST:",A2)
      READ(1,*)IREC1,IREC2
      IF((IREC1.LT.0).OR.(IREC1.GT.819))IREC1=0
      IF((IREC2.LT.0).OR.(IREC2.GT.819))IREC2=819
C
C         SWITCH 15  SUPPRESS PRINTOUT TO TERMINAL
C         SWITCH 14  ABORT MODAL COEFFICIENT ACQUISITION
C         SWITCH 13  SKIP DATA CALIBRATION
C         SWITCH 12  SKIP DIRECTIONAL COSINE CHECK
C         SWITCH 11  SKIP NIXIE TUBE DISPLAY
C         SWITCH  0  AUTOMATIC CIRCLE FIT ACQUISITION
C
      CALL KYBD(2HMS,31,IREC1)
      IIB8=1024
```

```
 2000 CONTINUE
      IF(IREC1.GT.IREC2)GO TO 1000
      IF(ISSW(14).LT.0)GO TO 1000
      IF(ISSW(11).LT.0)GO TO 2001
      CALL NIXIT(IREC1)
 2001 IREC1=IREC1+1
      CALL KYBD(2HMS,11,0)
C
C         GET DATA FROM HEADERS
C
      IIBS=IH(5)
      CALL CHKID(IT,ICIC)
      IF(ICIC.EQ.0)GO TO 2000
      CALL KYBD(2HBS,IIBS,0)
      IF(IH(36).NE.IZR)GO TO 2000
 2004 ID1=IH(19)
      IS=IH(45)
      IF(IS.GT.IP)GO TO 2000
C
C        CORRECT DATA WITH STORED CALIBRATION CONSTANT
C         OR CALIBRATION CURVE
C
      IF(ISSW(13))2030,2010
 2010 CONTINUE
      IF(RH(3).GT.0.0)GO TO 2030
      IRCAL=IFIX(ABS(RH(3)))
      WRITE(1,2012)IRCAL
 2012 FORMAT(/,"CALIBRATION RECORD IS ",I4)
      IF(ICUR.EQ.IRCAL)GO TO 2020
      CALL FNDFP(1,IPTR)
      CALL KYBD(2HMS,31,IRCAL)
      CALL KYBD(2HMS,11,1)
      CALL KYBD(2HMS,31,IPTR)
      ICUR=IRCAL
 2020 CONTINUE
      CALL KYBD(2H: ,1)
C
C       SWITCH 15 ON  SUPRESS OUTPUT TO TERMINAL DURING AUTO SEARCH
C
 2030 IF(ISSW(15))2060,2040
 2040 CALL IOSW(NU,0)
      WRITE(NU,2050)ID1,IS
 2050 FORMAT(A2,I5)
 2060 DO 2220 I=1,NM
      IBW=IB(I)
      NC=NCN(I)
      CALL GET(0,NC,X,Y)
C
C        MAGNITUDE
C
      R=ABS(SQRT(X*X+Y*Y))
      ANG=ATAN2(Y,X)
      IF(IANS.EQ.1)GO TO 2140
C
C      REAL PART
C
      R=X
      ANG=1.5707963
      IF(IANS.EQ.3)GO TO 2140
C
```

```
C        IMAGINARY PART
C
      R=Y
      ANG=1.5707963
      IF(IANS.EQ.2)GO TO 2140
      IF(IBW.EQ.0)GO TO 2140
C
C         CIRCLE FIT AND INTERACTIVE EDITING
C
 2070 CALL CIR(NC,IBW,X1,Y1,R)
      R=ABS(R)
      X=X-X1
      Y=Y-Y1
      ANG=ATAN2(Y,X)
C
C        SWITCH 0 ON     NO DISPLAY    AUTOMATIC CIRCLE FIT
C
      IF(ISSW(0))2110,2080
 2080 CALL KYBD(2HX),1)
      IZ1=33
      IZ2=NC-IBW
      IZ3=NC+IBW
      IZ4=IZ2-15
      IZ5=IZ3+15
      Z1=0.0
      DO 2090 J=1,IZ1
      Z1=Z1+.2
      Z2=R*SIN(Z1)+X1
      Z3=R*COS(Z1)+Y1
 2090 CALL PUT(1,J,Z2,Z3)
      WRITE(1,2091)IBELL
C
C        CIRCLE FIT MONITOR "D"
C
 2091 FORMAT("*D",A2)
      CALL TTYIN(LINE)
 2100 CALL TEST(1,IST,LOG)
C
C         CIRCLE FIT DISPLAY
C
      CALL KDIS(0,IZ2,IZ3,4)
      CALL KDIS(1,1,IZ1,4)
      CALL KDIS(0,IZ4,IZ5,4)
      CALL KDIS(0,IZ2,IZ3,4)
      IF(IST)2100,2110,2110
 2110 CALL CODE
      READ(LINE,1120)IL
      IF(IL.EQ.2HCL)GO TO 2130
      IF(IL.EQ.2H_ )GO TO 2125
      IF(IL.EQ.2HA-)GO TO 2112
      IF(IL.EQ.2H/R)GO TO 2114
      CALL CODE
      READ(LINE,*)IPAR1,IPAR2,IPAR3,IPAR4
      IBW=IPAR1
      IF(IPAR1)2135,2120,2070
 2112 NC=NCN(I)
      GO TO 2070
 2114 NCN(I)=NC
      IB(I)=IBW
      GO TO 2070
```

```
 2120 R=Y
      GO TO 2140
 2125 CALL CODE
      READ(LINE1,*)IPAR2
      NC=NC+IPAR2
      GO TO 2070
 2130 R=0
 2135 R=R*2.0
 2140 CALL KYBD(2HBS,IBS,0)
C
C         MODAL COEFFICIENT IS PROPORTIONAL TO DIAMETER
C
      RMAX=RMM(I)
      IF(RH(3).GT.0.0)R=R*RH(3)
      IF(ANG.GE.0)GO TO 2143
      R=(-1.0)*R
      ANG=ANG+3.14159265
 2143 L1=IFIX(ANG*57.295774)
C
C         CORRECT FOR TRANSDUCER ORIENTATION
C
      IF((ID1.EQ.2HX-).OR.(ID1.EQ.2H-1)) GO TO 2160
      IF((ID1.EQ.2HX ).OR.(ID1.EQ.2H1 ))GO TO 2170
      IF((ID1.EQ.2HY-).OR.(ID1.EQ.2H-2))GO TO 2180
      IF((ID1.EQ.2HY ).OR.(ID1.EQ.2H2 ))GO TO 2190
      IF((ID1.EQ.2HZ-).OR.(ID1.EQ.2H-3))GO TO 2200
      IF((ID1.EQ.2HZ ).OR.(ID1.EQ.2H3 ))GO TO 2210
C
C         DIRECTIONAL COSINE CHECK
C
      IF(ISSW(12))2144,2149
 2144 CONTINUE
      IF(ID1.NE.2HD )GO TO 2149
      PI=3.14159265
      DO 2145 IM=1,3
      IM3=IM+3
      R1=R*COS(RH(IM3)*PI/180.0)
      CALL RWCMC(IM,R1,L1,I,IS,IP,IBM,RMAX,0)
 2145 CONTINUE
      GO TO 2215
 2149 CONTINUE
      WRITE(1,2150)
 2150 FORMAT(/,"ERROR-WRONG COORDINATE CODE")
      CALL KYBD(2HMS,1)
      GO TO 2000
 2160 R=-R
 2170 CALL RWCMC(1,R,L1,I,IS,IP,IBM,RMAX,0)
      GO TO 2215
 2180 R=-R
 2190 CALL RWCMC(2,R,L1,I,IS,IP,IBM,RMAX,0)
      GO TO 2215
 2200 R=-R
 2210 CALL RWCMC(3,R,L1,I,IS,IP,IBM,RMAX,0)
 2215 CONTINUE
C
C         RMM ARRAY HAS THE SCALE FACTOR FOR
C          EACH MODE---VALUES ARE STORED AS
C         NUMBERS FROM 1 TO 2000
C
      RMM(I)=RMAX
```

```
 2220 CONTINUE
      GO TO 2000
C
C       STORE AND READ SET-UP AND MODAL DATA TO AND FROM DISC
C
C       READ
C
 6000 CALL KYBD(2HMS,35,1)
      CALL KYBD(2HMS,25)
      IF(IPAR1.EQ.-9999)GO TO 9011
      IF((IPAR1.GE.0).AND.(IPAR1.LE.800)) CALL KYBD(2HMS,31,IPAR1)
      IF((IPAR1.LT.0).OR.(IPAR1.GT.800))GO TO 6800
      CALL KYBD(2HMS,11,0)
      CALL KYBD(2HMS,31,-1,1)
      CALL RWCOM(-1)
      IF(ICOMM.NE.12345)GO TO 6800
      CALL KYBD(2HMS,11,ION)
      CALL RWCOM(0)
      IF(ICOMM.NE.12345)GO TO 6800
      NMP=0
      IRJ=ICM
      CALL KYBD(2HMS,11,IRJ)
      IRJ=IRJ-1
 6100 DO 6200 I=IBM,IRJ
 6200 CALL KYBD(2HMS,11,I)
      CALL KYBD(2HMS,35,1)
      CALL KYBD(2HMS,15)
      WRITE(1,1235)(IT(I),I=1,5)
 1235 FORMAT(/,"TEST ID IS",23X,5A2)
      GO TO 1000
C
C       STORE
C
 6500 CALL KYBD(2HMS,35,1)
      CALL KYBD(2HMS,25)
      IF(IPAR1.EQ.-9999)GO TO 9011
      IF((IPAR1.GE.0).AND.(IPAR1.LE.800))CALL KYBD(2HMS,31,IPAR1)
      IF((IPAR1.LT.0).OR.(IPAR1.GT.800))GO TO 6800
      IL=2H**
      CALL RWCOM(1)
      IH(6)=52525B
      IH(9)=10
      IH(10)=IT(1)
      IH(11)=IT(2)
      IH(12)=IT(3)
      IH(13)=IT(4)
      IH(14)=IT(5)
      IH(34)=2H71
      CALL KYBD(2HMS,21,ION)
      CALL KYBD(2HMS,21,ICM)
      IH(34)=2H72
      IRJ=ICM-1
      IPAR1=IPAR1+2
      DO 6700 I=IBM,IRJ
      IPAR1=IPAR1+1
 6700 CALL KYBD(2HMS,21,I)
      WRITE(1,6701)IPAR1
 6701 FORMAT(/,"NEXT DATA RECORD IS ",I4)
      CALL KYBD(2HMS,35,1)
      CALL KYBD(2HMS,15)
```

```
      GO TO 1000
 6800 WRITE(1,6801)
 6801 FORMAT(/,"ERROR-INVALID DATA RECORD")
      NMP=0
      ICOMM=12345
      GO TO 1000
C**********************************************************************
C          EXIT TO OTHER OVERLAYS
C**********************************************************************
 9001 I=1
      IFLAG=1
      GO TO 9900
 9002 I=2
      IFLAG=1
      GO TO 9900
 9003 I=3
      IFLAG=1
      GO TO 9900
 9004 I=4
      IFLAG=1
      GO TO 9900
 9005 I=5
      IFLAG=1
      GO TO 9900
 9006 I=6
      IFLAG=1
      GO TO 9900
 9007 I=7
      IFLAG=1
      GO TO 9900
 9008 I=8
      IFLAG=1
      GO TO 9900
 9009 I=9
      IFLAG=92
      GO TO 9900
 9010 I=10
      IFLAG=92
      GO TO 9900
 9011 I=11
      IFLGA=1
      GO TO 9900
 9900 CONTINUE
      CALL RWCOM(1)
      CALL KYBD(2HMS,38,I)
      CALL OVLD(9)
 9995 CONTINUE
      IL=2H**
      IF(ICOMM.EQ.12345)CALL RWCOM(1)
      CALL KYBD(2HBS,IBS,0)
      RETURN
      END
      END$
```

```
$Y904  T=00004 IS ON CR00103 USING 00093 BLKS R=0793

FTN4
      SUBROUTINE Y0009(INTOT,IPAR)
C
C        THIS PROGRAM IS STORED UNDER $Y904
C
C*************************************************************************
C
C       PROGRAMMER:  R.J.ALLEMANG
C                    MAIL LOCATION # 72
C                    UNIVERSITY OF CINCINNATI
C                    CINCINNATI, OHIO  45221
C                    513-475-6670
C
C       REVISION DATE:  NOV 20,1979
C
C*************************************************************************
      DIMENSION IPAR(6),LINE(36),LINE1(35),IZ(10),INQ(6)
     1,IDIV(1),ICMMD(26),IH(1),IX1(1),IY1(1),IDX(1),IDY(1)
     2,IC1(1),IPTCM(1),LO(3),LABEL(20)
      EQUIVALENCE (LINE(2),LINE1)
      COMMON ICOMM,MANRE,MDVA,BETA,IBLS,IT(5),ID(3),IP,NUMPT
     1,NM,ICON,NCOM,XXX(3,10),IX(3,10),IC(10),NMP,XR(3),A(2,3)
     2,O(3),IB(10),NCN(10),SF(2),XXA(2,3),YYA(2,3)
     3,FSHFT,DF,MCF,IZR,IL,IPAR1,IPAR2,IPAR3,IPAR4,IPAR5,IPAR6
     4,IFLAG,NS,NE,RMM(10),FRQ(10),ZETA(10)
      EXTERNAL HDR8,DTAD0,NMAX
      DATA IDZ/00/,INZ1/0/,SCALE/32760./
      DATA ICMMD/2HD ,2HV ,2H% ,2HEX,2H: ,
     12HM ,2H_ ,2HRO,2HA-,2HAM,
     22HCH,2HSP,2HX(,
     32HX),2HCV,2H( ,2HB ,2HL ,
     42HW ,2HI ,2HK ,2HA+,2H/L,
     52H? ,2H/.,2HX /
C*******************************************************************
C        UNIVERSITY OF CINCINNATI/LEUVEN MODAL ANALYSIS PROGRAM
C
C        DISPLAY PROGRAM
C*************************************************************************
      IBELL=7B
      IPAGE=15414B
      CALL SETAD(HDR8,IH,-8,0)
      ICOMM=0
      IBS=1024
      CALL KYBD(2HBS,IBS,0)
      CALL GETI(NMAX,IBLM)
      ION=IBLM-1
      ICM=ION-1
      IBM=2
      I=ION*IBS+270
      CALL SETAD(DTAD0,IPTCM,I,-1)
      INTPT=0
      CALL RWCOM(0)
C
C        IF PROGRAM REQUIRES INITIALIZATION, LOAD Y 91
C
      IF(ICOMM.EQ.12345)GO TO 900
      CALL KYBD(2HMS,38,-4,1)
      CALL OVLD(9)
```

```
  900 CONTINUE
      CALL SETAD(DTAD0,IX1,0,-1)
      CALL SETAD(DTAD0,IY1,256,-1)
      CALL SETAD(DTAD0,IDX,512,-1)
      CALL SETAD(DTAD0,IDY,768,-1)
      CALL SETAD(DTAD0,IC1,1024,-1)
      CALL SETAD(DTAD0,IDIV,1536,-1)
      IDZ=0
      IDIV(22)=0
      IDIV(23)=0
      IDIV(24)=0
      IDIV(25)=0
      SF1=.1
      IANSPD=4
      NMP=0
      NMP1=0
      NPD=2
      IKZ=1
      IFLG3=0
      IF(IFLAG.EQ.1)GO TO 1130
C***********************************************************************
C        DISPLAY PROGRAM INFO
C
C        LIST OF VARIABLES:
C
C        NMP1=                   LAST MODE WHICH DISPLAY WAS CALCULATED FOR
C
C        NMP=                    CURRENT REQUESTED DISPLAY MODE
C
C        NS1=                    THE NUMBER OF FRAMES DISPLAYED OF EACH
C                                DEFORMATION
C
C        INZ1=0                  ANIMATED DEFORMATIONS WITH UNDEFORMED
C        INZ1=1                  STILL DEFORMATION WITH UNDEFORMED
C        INZ1=2                  ANIMATED DEFORMATIONS ONLY
C        INZ1=3                  STILL DEFORMATION ONLY
C
C        IDZ=0                   UNDEFORMED SHAPE ONLY
C        IDZ=1                   DISPLAY ACCORDING TO INZ1 PARAMETER
C
C        IFLG3=0                 A DISPLAY HAS NOT BEEN PREVIOUSLY CALCULATED
C        IFLG3=1                 A DISPLAY HAS BEEN PREVIOUSLY CALCULATED
C
C        IFLG4=0                 A FULL DISPLAY HAS BEEN REQUESTED
C        IFLG4=1                 A PARTIAL DISPLAY HAS BEEN REQUESTED
C
C        IKZ=0                   THE REQUESTED MODE IS THE SAME AS PREVIOUS
C        IKZ=1                   THE REQUESTED MODE IS DIFFERENT
C
C        IX1                     X COORDINATES OF THE DISPLAY (UNDEFORMED)
C        IY1                     Y COORDINATES OF THE DISPLAY (UNDEFORMED)
C        IDX                     X COORDINATES OF THE DISPLAY (DEFORMED)
C        IDY                     X COORDINATES OF THE DISPLAY (DEFORMED)
C        IC1                     CONNECTIVITY FILE FOR CURRENT DISPLAY
C        IPTCM                   POINT LOCATION BY COMPONENT NUMBER FILE
C
C        IFLG5=0                 AUTOMATIC EXPANSION
C        IFLG5=1                 INHIBIT AUTOMATIC EXPANSION
C
C        IFLG6=0                 AUTOMATIC DISPLAY CENTERING
```

```
C        IFLG6=1            INHIBIT AUTOMATIC DISPLAY CENTERING
C
C        INTPT              POINT NUMBER OF POINT TO BE INTENSIFIED
C
C        IFLG8=0            NO DISPLAY OVERFLOW
C        IFLG8=1            OVERFLOW OF DISPLAY CALCULATION
C
C*********************************************************************
C
C        START OF MONITOR
C
C*********************************************************************
 1000 WRITE(1,1010)IBELL
 1010 FORMAT("*",A2)
      I=ISWR(177677B,0,0)
      IF((NPD.GT.510).OR.(NPD.LT.2)) NPD=2
      NS1=IANSPD*300/NPD
      IF(NS1.LE.0)NS1=1
      IF(NS1.GT.100)NS1=100
      L=0
      IPAR1=-9999
      IPAR2=-9999
      IPAR3=-9999
      IPAR4=-9999
      IPAR5=-9999
      IPAR6=-9999
 1020 DO 1030 I=1,36
 1030 LINE(I)=2H,,
 1040 CALL TTYIN(LINE)
 1042 CONTINUE
      IF(IFLG3.EQ.1)GO TO 1044
 1043 CALL TEST(1,IST,LOG)
      IF(IST.LT.0)GO TO 1043
      GO TO 1111
 1044 CONTINUE
      CALL SDISP(IX1(1),IY1(1),IDX(1),IDY(1),IC1(1),NPD,NMP,INTPT)
 1045 IF(L.GT.19)L=0
      L=L+1
      DO 1100 II=1,NS1
 1050 CALL TEST(1,IST,LOG)
 1060 IF((INZ1.EQ.2).OR.(INZ1.EQ.3)) GO TO 1070
C
C         DISPLAY UNDEFORMED SHAPE
C
 1065 CALL XDISP(32767,NPD)
 1070 IF(IDZ.EQ.0) GO TO 1090
C
C         DISPLAY ONE POSITION OF DEFORMED SHAPE
C
 1080 CALL XDISP(IDIV(L),NPD)
 1090 IF(IST.GE.0)GO TO 1110
      IF((INZ1.EQ.1).OR.(INZ1.EQ.3)) GO TO 1050
 1100 CONTINUE
      GO TO 1045
 1110 CALL TDISP
C
C        PROCESS NEW COMMAND
C
 1111 CONTINUE
      CALL CODE
```

```
      READ(LINE,1120)IL
      IF(ICOMM.EQ.12345)GO TO 1115
C
C       PUT A CHECK FOR ANY COMMANDS THAT ARE NOT TO BE
C           EXECUTED UNLESS ENOUGH SET-UP IS PRESENT
      DO 1112 I=1,12
      IF(IL.EQ.ICMMD(I))GO TO 1139
 1112 CONTINUE
      IF(IL.EQ.ICMMD(17))GO TO 1139
C
 1115 CONTINUE
 1120 FORMAT(A2)
      CALL CODE
      READ(LINE1,*)IPAR1,IPAR2,IPAR3,IPAR4,IPAR5,IPAR6
C**************************************************************************
C       MONITOR COMMAND TABLE
C**************************************************************************
 1130 IFLAG=0
      CALL RWCOM(1)
      IF(IL.EQ.2H**)GO TO 1000
      NCMMD=26
      DO 1138  I=1,NCMMD
      IF(IL.EQ.ICMMD(I))GO TO 1144
 1138 CONTINUE
 1139 WRITE(1,1140)
 1140 FORMAT(/,"ERROR-ILLEGAL COMMAND")
      GO TO 1000
 1144 IF(I.GT.10)GO TO 1146
      GO TO (2280,2250,2250,2500,2500,3000,3000,4500,4500,4000),I
 1146 I=I-10
      IF(I.GT.10)GO TO 1148
      GO TO (4000,7000,6000,6500,5000,9995,1200,1200,9002,9001),I
 1148 I=I-10
      GO TO (9001,9003,9008,8000,7500,9011),I
 1200 CONTINUE
      IF(IPAR1.EQ.37)GO TO 9005
      IF(IPAR1.EQ.10)GO TO 9006
      IF(IPAR1.EQ.6)GO TO 9007
      GO TO 1139
C
C         JUMP HERE FOR DISPLAY COMMAND ERROR
C
 1900 CONTINUE
      WRITE(1,1902)IBELL
 1902 FORMAT(/,"ERROR-DISPLAY REQUIRES FURTHER INPUT",A2,/)
      GO TO 1000
 1910 CONTINUE
      WRITE(1,1912)IBELL
 1912 FORMAT(/,"ERROR-NO CURRENT DISPLAY",A2,/)
      GO TO 1000
C**************************************************************************
C         VIEW COMMAND
C
C         CALCULATE THE MATRIX TO CONVERT GLOBAL X,Y,Z TO
C           SCREEN X,Y OF THE 5460 DISPLAY UNIT
C**************************************************************************
 2250 CONTINUE
      IF(IFLG3.EQ.0)GO TO 1910
      IF(IPAR1.EQ.-9999)IPAR1=1
      IF(IPAR2.EQ.-9999)IPAR2=1
```

```
      IF(IPAR3.EQ.-9999)IPAR3=1
      Z1=IPAR1
      Z2=IPAR2
      Z3=IPAR3
      XL=SQRT(Z1*Z1+Z2*Z2+Z3*Z3)
      ST=Z2/XL
      CT=SQRT(Z1*Z1+Z3*Z3)/XL
      CP=0.
      SP=1.
      XL=Z1*Z1+Z3*Z3
      IF(XL.LT.0.0001)GO TO 2270
      XL=SQRT(XL)
      SP=Z3/XL
      CP=Z1/XL
C
C          THE FOLLOWING CODE ORIENTS THE Y DIRECTION
C            OF THE GLOBAL COORDINATES TO THE Y DIRECTION
C            OF THE 5460 SCOPE UNIT
C
 2270 A(1,1)=+SP
      A(1,2)=0.0
      A(1,3)=-CP
      A(2,1)=-ST*CP
      A(2,2)=CT
      A(2,3)=-ST*SP
      IF(IPAR4.EQ.-9999)GO TO 2364
      GO TO 1000
C**********************************************************************
C           DISPLAY COMMAND
C*********************************************************************
 2280 CONTINUE
C
C        CHECK TO SEE IF DATA SET HAS BEEN ENTERED
C
      IF(ICOMM.NE.12345)GO TO 1900
      IF(NUMPT.EQ.1)GO TO 1900
      IF(ICON.EQ.0)GO TO 1900
      IF(NCOM.EQ.0)GO TO 1900
      IF(IPAR1+9999) 2300,2290,2300
 2290 INZ1=INZ1+1
      IF(INZ1.GE.4) INZ1=0
      IF(NMP.EQ.0)INZ1=0
      GO TO 1000
C**********************************************************************
 2300 CONTINUE
      IF(IABS(IPAR1).GT.NM)GO TO 1138
      IF(IPAR1.LT.0)IFLG3=0
      IF(IPAR1.LT.0)NMP1=0
      IF(IPAR1.LT.0)IPAR1=-IPAR1
      NMP=IPAR1
      INZ1=2
      IF(NMP.EQ.0)INZ1=0
C
C          CHECK FOR PARTIAL DISPLAY
C
      IF(IPAR2.EQ.-9999)IFLG4=0
      IF(IPAR2.EQ.-9999)GO TO 2306
      IF((IPAR2.LT.1).OR.(IPAR2.GT.4))GO TO 1900
      IFLG4=1
C
```

```
C         SET UP IZ ARRAY ACCORDINGLY
C
      IZ(1)=IPAR3
      IZ(2)=IPAR4
      IZ(3)=IPAR5
      IZ(4)=IPAR6
      IZ1=IPAR2+1
      DO 2302 I=IZ1,10
 2302 IZ(I)=0
      IFL=0
      DO 2304 I=1,10
 2304 IF((IZ(I).LT.0).OR.(IZ(I).GT.NCOM))IFL=1
      IF(IFL.EQ.1)GO TO 1900
      IFL=0
      GO TO 2310
 2306 CONTINUE
      DO 2308  I=1,10
 2308 IZ(I)=I
 2310 CONTINUE
C
      IKZ=1
      IF(NMP.EQ.0)IDZ=0
      IF(NMP.GT.0)IDZ=1
C
      IF(NMP1.EQ.NMP)IKZ=0
      IF(NMP.EQ.0)IKZ=0
      NMP1=NMP
      IF(IFLG4.EQ.1)IKZ=1
      IF(IFLG3.EQ.0)IKZ=1
C
      IF(IKZ.EQ.0)GO TO 1000
      IF(IFLG3.EQ.1)GO TO 2364
C*********************************************************************
C         CALCULATE THE LONGEST VECTOR IN X,Y,Z SPACE
C            IN ORDER TO INITIALLY SCALE THE DISPLAY
C*********************************************************************
 2360 CONTINUE
      SCALU=0.0
      SCALD=0.0
      XMAX=-1E30
      YMAX=-1E30
      ZMAX=-1E30
      XMIN=1E30
      YMIN=1E30
      ZMIN=1E30
      RMAX=1.0
      DO 2363 I=1,NUMPT
      CALL RWCMC(1,XXA(2,1),LO(1),NMP,I,IP,IBM,RMAX,1)
      CALL RWCMC(2,XXA(2,2),LO(2),NMP,I,IP,IBM,RMAX,1)
      CALL RWCMC(3,XXA(2,3),LO(3),NMP,I,IP,IBM,RMAX,1)
      CALL RWCOR(I,XXA(1,1),XXA(1,2),XXA(1,3),ICM,1)
      IZ5=IPTCM(I)
      IF((IZ5.LT.1).OR.(IZ5.GT.NCOM))GO TO 2363
C
C        ONLY CONSIDER POINTS WITH REQUESTED COMPONENTS
C
      DO 2371 IIR=1,NCOM
      IF(IZ(IIR).EQ.IZ5)GO TO 2372
 2371 CONTINUE
      GO TO 2363
```

```
 2372 CONTINUE
      IF(IC(IZ5).NE.0) GO TO 2361
C***********************************************************************
C        CONVERT CYLINDER COORDINATES TO RECTANGULAR
C
C***************************************************************
C
C       XXX( , )=        LOCAL ORIGINS WITH RESPECT TO GLOBAL
C                        ORIGIN AS INPUTTED IN Y0091
C                        NEEDED TO CREATE ABSOLUTE GEOMETRY
C
C       XXA(1, )=        LOCAL POINT COORDINATES
C       XXA(2, )=        LOCAL MODAL COEFFICIENTS
C
C       YYA(1, )=        GLOBAL POINT COORDINATES
C       YYA(2, )=        GLOBAL MODAL COEFFICIENTS
C
C***************************************************************
      Z1=XXA(2,1)
      Z2=XXA(1,2)/57.29577951
      Z3=COS(Z2)
      Z4=SIN(Z2)
      Z5=XXA(1,1)
      XXA(2,1)=Z1*Z3-XXA(2,2)*Z4
      XXA(2,2)=Z1*Z4+XXA(2,2)*Z3
      XXA(1,1)=Z5*COS(Z2)
      XXA(1,2)=Z5*SIN(Z2)
C
C        CONVERT FROM LOCAL TO GLOBAL COORDINATES USING
C          COMPONENT ORIGINS AND ORIENTATIONS
C
 2361 DO 2362 K=1,2
      DO  2362 II=1,3
      IZ1=IABS(IX(II,IZ5))
      Z1=IX(II,IZ5)/IZ1
      Z3=XXX(II,IZ5)
      IF(K.EQ.2)Z3=0
 2362 YYA(K,II)=XXA(K,IZ1)*Z1+Z3
C
C        FIND MAX AND MIN POINTS TO COMPUTE DISPLAY CENTER
C
      XMIN=AMIN1(XMIN,YYA(1,1))
      XMAX=AMAX1(XMAX,YYA(1,1))
      YMIN=AMIN1(YMIN,YYA(1,2))
      YMAX=AMAX1(YMAX,YYA(1,2))
      ZMIN=AMIN1(ZMIN,YYA(1,3))
      ZMAX=AMAX1(ZMAX,YYA(1,3))
C***********************************************************************
C        SF(1)=MAXIMUM UNDEFORMED VECTOR FROM GLOBAL ORIGIN
C        SF(2)=MAXIMUM DEFORMED VECTOR FROM GLOBAL ORIGIN
C***********************************************************************
C
C        CALCULATIONS ARE FROM (0,0,0) NOT THE DISPLAY ORIGIN
C
C***********************************************************************
      Z3=SQRT(YYA(2,1)**2+YYA(2,2)**2+YYA(2,3)**2)
      SCALD=AMAX1(SCALD,Z3)
      Z3=SQRT(YYA(1,1)**2+YYA(1,2)**2+YYA(1,3)**2)
      SCALU=AMAX1(SCALU,Z3)
 2363 CONTINUE
```

```
C
C          COMPUTE "O" VECTOR    ACTUAL 3-D DISPLAY ORIGIN
C
      O(1)=(XMAX+XMIN)/2.
      O(2)=(YMAX+YMIN)/2.
      O(3)=(ZMAX+ZMIN)/2.
C
C          USE SCALE FACTORS TO MAKE DEFORMED AND UNDEFORMED
C            VECTORS AS LARGE AS POSSIBLE
C
      IF(SCALU.EQ.0.0)SCALU=1.0
      IF(SCALD.EQ.0.0)SCALD=1.0
      SCALU=SCALE/SCALU
      SCALD=SCALE/SCALD
C**********************************************************************
C         START OF ACTUAL DISPLAY CALCULATION
C**********************************************************************
 2364 NPD=0
      SF(1)=SCALU
      SF(2)=SCALD
      CALL KYBD(2HCL,0)
      CALL KYBD(2HCL,1)
 2365 DO 2366 I=1,NUMPT
      IX1(I)=32760
 2366 IY1(I)=32760
      XMAX=-1E30
      YMAX=-1E30
      XMIN=1E30
      YMIN=1E30
      XAVG=0.0
      YAVG=0.0
C*****************************************************************
C         DISPLAY LOOP
C*****************************************************************
      RMAX=1.0
      DO 2380 J=1,ICON
      CALL RWCON(J,IZ3,ION,1)
      IZ6=IZ3
      IZ3=IABS(IZ3)
      IF((IZ3.EQ.0).OR.(IZ3.GT.NUMPT))WRITE(NU,2374)
 2374 FORMAT(/,"ERROR-CONNECTIVITY FILE")
      IF((IZ3.EQ.0).OR.(IZ3.GT.NUMPT))IFLG3=0
      IF((IZ3.EQ.0).OR.(IZ3.GT.NUMPT))GO TO 1000
      CALL RWCOR(IZ3,XXA(1,1),XXA(1,2),XXA(1,3),ICM,1)
      IZ5=IPTCM(IZ3)
      IF((IZ5 LT.1).OR.(IZ5.GT.NCOM))GO TO 2380
      DO 2367 II=1,NCOM
      IF(IZ(II).EQ.IZ5) GO TO 2369
 2367 CONTINUE
      GO TO 2380
C
C         THE COMPONENT NUMBER (IZ5) IS TO BE INCLUDED IN THE
C         NEW DISPLAY
C
 2369 NPD=NPD+1
      IC1(NPD)=IZ6
      IF((IX1(IZ3).NE.32760).AND.(IY1(IZ3).NE.32760)) GO TO 2380
      CALL RWCMC(1,XXA(2,1),LO(1),NMP,IZ3,IP,IBM,RMAX,1)
      CALL RWCMC(2,XXA(2,2),LO(2),NMP,IZ3,IP,IBM,RMAX,1)
      CALL RWCMC(3,XXA(2,3),LO(3),NMP,IZ3,IP,IBM,RMAX,1)
```

```
      IF(IC(IZ5).NE.0) GO TO 2370
C
C        CONVERTS CYLINDRICAL COORDINATES TO RECTANGULAR
C
      Z1=XXA(2,1)
      Z2=XXA(1,2)/57.29577951
      Z3=COS(Z2)
      Z4=SIN(Z2)
      Z5=XXA(1,1)
      XXA(2,1)=Z1*Z3-XXA(2,2)*Z4
      XXA(2,2)=Z1*Z4+XXA(2,2)*Z3
      XXA(1,1)=Z5*COS(Z2)
      XXA(1,2)=Z5*SIN(Z2)
C
C        CONVERTS LOCAL COORDINATES TO GLOBAL
C          ADJUSTMENT TO DISPLAY ORIGIN
C
 2370 DO 2375 I=1,2
      DO 2375 II=1,3
      IZ1=IABS(IX(II,IZ5))
      Z1=IX(II,IZ5)/IZ1
      Z2=O(II)
      Z3=XXX(II,IZ5)
      IF(I.EQ.2)Z3=0
      IF(I.EQ.2) Z2=0
 2375 YYA(I,II)=XXA(I,IZ1)*Z1+Z3-Z2
C
C        CONVERTS GLOBAL X,Y,Z COORDINATES TO X,Y SCREEN
C          COORDINATES OF THE 5460 DISPLAY UNIT
C          WITH THE PROPER VIEWING POSITION
C
      DO 2380 I=1,2
      X=(A(1,1)*YYA(I,1)+A(1,2)*YYA(I,2)+A(1,3)*YYA(I,3))*SF(I)
      Y=(A(2,1)*YYA(I,1)+A(2,2)*YYA(I,2)+A(2,3)*YYA(I,3))*SF(I)
      X=AMAX1(X,-32765.)
      Y=AMAX1(Y,-32765.)
      X=AMIN1(X,32765.)
      Y=AMIN1(Y,32765.)
      IF(I.EQ.2)GO TO 2376
      XMAX=AMAX1(XMAX,X)
      XMIN=AMIN1(XMIN,X)
      YMAX=AMAX1(YMAX,Y)
      YMIN=AMIN1(YMIN,Y)
 2376 CONTINUE
      IF(I.EQ.1)IX1(IZ3)=X
      IF(I.EQ.1)IY1(IZ3)=Y
      IF(I.EQ.2)IDX(IZ3)=X
      IF(I.EQ.2)IDY(IZ3)=Y
 2380 CONTINUE
C
C        CENTER DISPLAY
C
      IF(IFLG6.EQ.1)GO TO 2382
      XAVG=(XMAX+XMIN)/2.
      YAVG=(YMAX+YMIN)/2.
      DO 2378  I=1,NUMPT
      IX1(I)=FLOAT(IX1(I))-XAVG
      IY1(I)=FLOAT(IY1(I))-YAVG
 2378 CONTINUE
 2382 CONTINUE
```

```
      IFLG6=0
C
C        MAXIMIZE DISPLAY TO 80 %
C
      XMAX=ABS(XMAX-XAVG)
      XMIN=ABS(XMIN-XAVG)
      YMAX=ABS(YMAX-YAVG)
      YMIN=ABS(YMIN-YAVG)
      XMAX=AMAX1(XMAX,XMIN,YMAX,YMIN)
C
      Z1=26000./XMAX
C
C        CALCULATE DIVISORS USED FOR DISPLAY POSITIONS
C          OF EACH FRAME
C
 2390 DR=-.314159265
      R=-DR
      DO 2400 I=1,20
      R=R+DR
      IDIV(I)=IFIX(1./(SF1*COS(R)))
 2400 CONTINUE
C
C        IDIV(21)=NPD ONLY SO THAT THE VARIABLE
C           NPD WILL BE AVAILABLE IN Y 94
C
      IDIV(21)=NPD
C
      IFLG3=1
      IKZ=1
      IF(IFLG5.EQ.1)GO TO 2602
C
      IF(NMP.EQ.0)GO TO 2452
      IF(ISSW(14).LT.0)GO TO 2452
      CALL IDSW(NU,0)
      WRITE(NU,2450)FRQ(NMP)
 2450 FORMAT(/,F12.4," HERTZ",/)
 2452 CONTINUE
      GO TO 2510
C
C        EXPAND COMMAND
C
 2500 Z1=IPAR1
      Z1=Z1/100.
 2510 SF(1)=Z1*SF(1)
      SF(2)=SF(2)*Z1
      IFLG8=0
      DO 2600 I=1,NUMPT
      X1=FLOAT(IX1(I))*Z1
      Y1=FLOAT(IY1(I))*Z1
      DX=FLOAT(IDX(I))
      DY=FLOAT(IDY(I))
      X1=AMIN1(X1,32765.)
      Y1=AMIN1(Y1,32765.)
      DX=AMIN1(DX,32765.)
      DY=AMIN1(DY,32765.)
      X1=AMAX1(X1,-32765.)
      Y1=AMAX1(Y1,-32765.)
      DX=AMAX1(DX,-32765.)
      DY=AMAX1(DY,-32765.)
      IX1(I)=X1
```

```
      IY1(I)=Y1
      IDX(I)=DX
      IDY(I)=DY
      IF((DX.EQ.32765.).OR.(DX.EQ.-32765.))IFLG8=1
      IF((DY.EQ.32765.).OR.(DY.EQ.-32765.))IFLG8=1
 2600 CONTINUE
      IF(IFLG8.EQ.1)WRITE(NU,2698)IBELL
 2698 FORMAT(/,"ERROR-DISPLAY OVERFLOW",A2)
 2602 CONTINUE
      IFLG5=0
      GO TO 1000
C
C        MOVE COMMAND
C
 3000 IF(IPAR2.EQ.-9999) GO TO 3070
      IZ1=FLOAT(IPAR1)*320.
      IZ2=FLOAT(IPAR2)*320.
      DO 3050 I=1,NUMPT
      IX1(I)=IX1(I)+IZ1
      IY1(I)=IY1(I)+IZ2
 3050 CONTINUE
C
C        MOVE THE DISPLAY IPAR1 % UP AND IPAR2 % RIGHT
C        IF THE PARAMETERS ARE NEGATIVE , GO THE
C        OPPOSITE DIRECTION
C
      GO TO 1000
 3070 CALL RWCOR(IPAR1,XXA(1,1),XXA(1,2),XXA(1,3),ICM,1)
      IZ5=IPTCM(IPAR1)
      IF(IC(IZ5).NE.0) GO TO 3100
      Z5=XXA(1,1)
      Z2=XXA(1,2)
      Z2=Z2/57.2957791
      XXA(1,1)=Z1*COS(Z2)
      XXA(1,2)=Z1*SIN(Z2)
 3100 DO 3200 I=1,3
      IZ1=IABS(IX(I,IZ5))
      Z4=IX(I, IZ5)/IZ1
 3200 O(I)=XXA(1,IZ1)*Z4+XXX(I,IZ5)
C
C         IFLG6 = 1  INHIBITS AUTO CENTERING
C
      IFLG6=1
      GO TO 2364
C
C        AMPLITUDE COMMAND
C
 4000 IF(IPAR1.LE.0)IPAR1=100
      Z1=IABS(IPAR1)
      SF1=SF1*Z1/100.
C
C         IFLG5 = 1  INHIBITS AUTO EXPANSION
C
      IFLG5=1
      GO TO 2390
C
C        ROTATE COMMAND
C
 4500 Z1=IPAR1
      Z1=Z1/57.29577951
```

```
      Z2=COS(Z1)
      Z3=SIN(Z1)
      DO 4600 I=1,NUMPT
      Z4=IX1(I)
      Z5=IDX(I)
      IX1(I)=Z2*Z4-Z3*FLOAT(IY1(I))
      IDX(I)=Z2*Z5-Z3*FLOAT(IDY(I))
      IY1(I)=Z2*FLOAT(IY1(I))+Z3*Z4
 4600 IDY(I)=Z2*FLOAT(IDY(I))+Z3*Z5
      GO TO 1000
C
C        CONVOLUTION COMMAND
C
 5000 IANSPD=IPAR1
      GO TO 1000
C
C        STORE AND READ SET-UP AND MODAL DATA TO AND FROM DISC
C
C        READ
C
 6000 CALL KYBD(2HMS,35,1)
      CALL KYBD(2HMS,25)
      IF(IPAR1.EQ.-9999)GO TO 9011
      IF((IPAR1.GE.0).AND.(IPAR1.LE.800))CALL KYBD(2HMS,31,IPAR1)
      IF((IPAR1.LT.0).OR.(IPAR1.GT.800))GO TO 6800
      CALL KYBD(2HMS,11,0)
      CALL KYBD(2HMS,31,-1,1)
      CALL RWCOM(-1)
      IF(ICOMM.NE.12345)GO TO 6800
      CALL KYBD(2HMS,11,ION)
      CALL RWCOM(0)
      IF(ICOMM.NE.12345)GO TO 6800
      NMP1=0
      NMP=0
      IFLG3=0
      IRJ=ICM
      CALL KYBD(2HMS,11,IRJ)
      IRJ=IRJ-1
 6100 DO 6200 I=IBM,IRJ
 6200 CALL KYBD(2HMS,11,I)
      CALL KYBD(2HMS,35,1)
      CALL KYBD(2HMS,15)
      WRITE(1,1235)(IT(I),I=1,5)
 1235 FORMAT(/,"TEST ID IS",23X,5A2)
      GO TO 1000
C
C        STORE
C
 6500 CALL KYBD(2HMS,35,1)
      CALL KYBD(2HMS,25)
      IF(IPAR1.EQ.-9999)GO TO 9011
      IF((IPAR1.GE.0).AND.(IPAR1.LE.800))CALL KYBD(2HMS,31,IPAR1)
      IF((IPAR1.LT.0).OR.(IPAR1.GT.800))GO TO 6800
      IL=2H**
      CALL RWCOM(1)
      IH(6)=52525B
      IH(9)=10
      IH(10)=IT(1)
      IH(11)=IT(2)
      IH(12)=IT(3)
```

```
      IH(13)=IT(4)
      IH(14)=IT(5)
      IH(34)=2H71
      CALL KYBD(2HMS,21,ION)
      CALL KYBD(2HMS,21,ICM)
      IH(34)=2H72
      IRJ=ICM-1
      IPAR1=IPAR1+2
      DO 6700 I=IBM,IRJ
      IPAR1=IPAR1+1
 6700 CALL KYBD(2HMS,21,I)
      WRITE(1,6701)IPAR1
 6701 FORMAT(/,"NEXT DATA RECORD IS ",I4)
      CALL KYBD(2HMS,35,1)
      CALL KYBD(2HMS,15)
      GO TO 1000
 6800 WRITE(1,6801)
 6801 FORMAT(/,"ERROR-INVALID DATA RECORD")
      NMP1=0
      NMP=0
      IFLG3=0
      ICOMM=12345
      GO TO 1000
C
C         AUTO SCALE OF DISPLAY
C
 7000 Z1=IPAR1
      IF(Z1.LT.2000)GO TO 7100
      IF(Z1.GT.5000)GO TO 7100
      SCALE=Z1*10.
 7100 CONTINUE
      GO TO 1000
C
C        ENABLE POINT LABELING FOR PLOT
C
 7500 CONTINUE
      IF(IPAR1.EQ.-9999)IPAR1=100
      IF(IPAR2.EQ.-9999)IPAR2=100
      IF(IPAR3.EQ.-9999)IPAR3=100
      IF(IPAR4.EQ.-9999)IPAR4=1
      IF(IPAR5.EQ.-9999)IPAR5=250
      IDIV(22)=IPAR1
      IDIV(23)=IPAR2
      IDIV(24)=IPAR3
      IDIV(25)=IPAR4
      IDIV(26)=IPAR5
      IDIV(27)=1
      GO TO 1000
C
C        INPUT POINT TO BE INTENSIFIED
C
 8000 CONTINUE
      INTPT=IPAR1
      GO TO 1000
C*************************************************************************
C         EXIT TO OTHER OVERLAYS
C*************************************************************************
 9001 I=1
      GO TO 9900
 9002 I=2
```

```
      GO TO 9900
 9003 I=3
      GO TO 9900
 9004 I=4
      GO TO 9900
 9005 I=5
      GO TO 9900
 9006 I=6
      GO TO 9900
 9007 I=7
      GO TO 9900
 9008 I=8
      GO TO 9900
 9011 I=11
      GO TO 9900
 9900 CONTINUE
      IFLAG=1
      CALL RWCOM(1)
      CALL KYBD(2HMS,38,I)
      CALL OVLD(9)
 9995 CONTINUE
      IL=2H##
      IF(ICOMM.EQ.12345)CALL RWCOM(1)
      CALL KYBD(2HBS,IBS,0)
      RETURN
      END
      END$
```

```
$Y908  T=00004 IS ON CR00103 USING 00026 BLKS R=0219

FTN4
      SUBROUTINE Y0009(INTOT,IPAR)
C
C        THIS PROGRAM IS STORED UNDER $Y908
C
C*************************************************************************
C
C       PROGRAMMER:  R.J.ALLEMANG
C                    MAIL LOCATION # 72
C                    UNIVERSITY OF CINCINNATI
C                    CINCINNATI, OHIO  45221
C                    513-475-6670
C
C       REVISION DATE:   DEC 17, 1979
C
C*************************************************************************
      DIMENSION IPAR(6),LINE(36),LINE1(35),IZ(10),INQ(6)
     1,IDIV(1),ICMMD(24),IH(1),IX1(1),IY1(1),IDX(1),IDY(1)
     2,IC1(1),IPTCM(1),LABEL(20),IPOINT(1)
      EQUIVALENCE (LINE(2),LINE1)
      COMMON ICOMM,MANRE,MDVA,BETA,IBLS,IT(5),ID(3),IP,NUMPT
     1,NM,ICON,NCOM,XXX(3,10),IX(3,10),IC(10),NMP,XR(3),A(2,3)
     2,O(3),IB(10),NCN(10),SF(2),XXA(2,3),YYA(2,3)
     3,FSHFT,DF,MCF,IZR,IL,IPAR1,IPAR2,IPAR3,IPAR4,IPAR5,IPAR6
     4,IFLAG,NS,NE,RMM(10),FRQ(10),ZETA(10)
      EXTERNAL HDR8,DTAD0,NMAX
      DATA ICMMD/2HD ,2HV ,2H% ,2HEX,2H: ,
     12HM ,2H_ ,2HRO,2HA-,2HAM,
     22HCH,2HSP,2HX(,
     32HX),2HCV,2H( ,2HB ,2HL ,
     42HW ,2HI ,2HK ,2HA+,2H/L,
     52H/./
C*************************************************************************
C        UNIVERSITY OF CINCINNATI/LEUVEN MODAL ANALYSIS PROGRAM
C
C        MOVIE PROGRAM
C*************************************************************************
      IBELL=7B
      IPAGE=15414B
      CALL SETAD(HDR8,IH,-8,0)
      ICOMM=0
      IBS=1024
      CALL KYBD(2HBS,IBS,0)
      CALL GETI(NMAX,IBLM)
      ION=IBLM-1
      ICM=ION-1
      IBM=2
      CALL RWCOM(0)
C
C        IF INITIALIZATION IS REQUIRED, LOAD Y 91
C
      IF(ICOMM.EQ.12345)GO TO 900
      CALL KYBD(2HMS,38,-8,1)
      CALL OVLD(9)
  900 CONTINUE
      IF(IFLAG.EQ.1)GO TO 1130
C*************************************************************************
C       START OF MONITOR
```

```
C**********************************************************************
 1000 WRITE(1,1010)IBELL
 1010 FORMAT("*",A2)
      I=ISWR(177677B,0,0)
      IPAR1=-9999
      IPAR2=-9999
      IPAR3=-9999
      IPAR4=-9999
      IPAR5=-9999
      IPAR6=-9999
 1020 DO 1030 I=1,36
 1030 LINE(I)=2H,,
 1040 CALL TTYIN(LINE)
 1042 CALL TEST(1,IST,LOG)
      IF(IST.LT.0)GO TO 1042
      CALL CODE
      READ(LINE,1120)IL
      IF(ICOMM.EQ.12345)GO TO 1115
C
C        PUT A CHECK FOR ANY COMMANDS THAT ARE NOT TO BE
C            EXECUTED UNLESS ENOUGH SET-UP IS PRESENT
C
 1115 CONTINUE
 1120 FORMAT(A2)
      CALL CODE
      READ(LINE1,*)IPAR1,IPAR2,IPAR3,IPAR4,IPAR5,IPAR6
C**********************************************************************
C        MONITOR COMMAND TABLE
C**********************************************************************
 1130 IFLAG=0
      CALL RWCOM(1)
      IF(IL.EQ.2H##)GO TO 1000
      NCMMD=24
      DO 1138  I=1,NCMMD
      IF(IL.EQ.ICMMD(I))GO TO 1144
 1138 CONTINUE
 1139 WRITE(1,1140)
 1140 FORMAT(/,"ERROR-ILLEGAL COMMAND")
      GO TO 1000
 1144 IF(I.GT.10)GO TO 1146
      GO TO (9004,9004,9004,9004,9004,9004,9004,9004,9004,9004),I
 1146 I=I-10
      IF(I.GT.10)GO TO 1148
      GO TO (9004,9004,6000,6500,9004,9995,1100,1100,9002,9001),I
 1148 I=I-10
      GO TO (9001,9003,3000,9004),I
 1100 CONTINUE
      IF(IPAR1.EQ.37)GO TO 9005
      IF(IPAR1.EQ.10)GO TO 9006
      IF(IPAR1.EQ.6)GO TO 9007
      GO TO 1139
C
C          ASCII TEXT TO 5460 CRT SCREEN
C
 3000 CONTINUE
      IF(IPAR3.EQ.-9999)IPAR3=5000
      IF(IPAR2.EQ.-9999)IPAR2=500
      ICC=0
      IF(IPAR1.EQ.-9999)IPAR1=0
      IF(IPAR1.GT.NM)IPAR1=0
```

```
      IF(IPAR1.LT.0)GO TO 3100
      IF(IPAR1.GT.0)A1=FRQ(IPAR1)
      IF((IPAR1.GT.0).AND.(IPAR1.LE.NM))ICC=1
      CALL CRT(IPAR2,IPAR3,ICC,A1)
      GO TO 1000
 3100 CONTINUE
      IPAR1=IABS(IPAR1)
      IF(IPAR1.GT.820)GO TO 1000
      CALL KYBD(2HMS,31,IPAR1)
      CALL KYBD(2HMS,11)
      IPNT=IH(13)
      IF(IH(10).NE.2HCH)GO TO 1000
      CALL TTYIN(LINE)
 3110 CALL TEST(1,IST,LOG)
      CALL KDIS(0,1,IPNT,12)
      IF(IST.LT.0)GO TO 3110
      GO TO 1000
C
C       STORE AND READ SET-UP AND MODAL DATA TO AND FROM DISC
C
C       READ
C
 6000 CALL KYBD(2HMS,35,1)
      CALL KYBD(2HMS,25)
      IF((IPAR1.GE.0).AND.(IPAR1.LE.800))CALL KYBD(2HMS,31,IPAR1)
      IF((IPAR1.LT.0).OR.(IPAR1.GT.800))GO TO 6800
      CALL KYBD(2HMS,11,0)
      CALL KYBD(2HMS,31,-1,1)
      CALL RWCOM(-1)
      IF(ICOMM.NE.12345)GO TO 6800
      CALL KYBD(2HMS,11,ION)
      CALL RWCOM(0)
      IF(ICOMM.NE.12345)GO TO 6800
      NMP=0
      IRJ=ICM
      CALL KYBD(2HMS,11,IRJ)
      IRJ=IRJ-1
 6100 DO 6200 I=IBM,IRJ
 6200 CALL KYBD(2HMS,11,I)
      CALL KYBD(2HMS,35,1)
      CALL KYBD(2HMS,15)
      WRITE(1,1235)(IT(I),I=1,5)
 1235 FORMAT(/,"TEST ID IS",23X,5A2)
      GO TO 1000
C
C       STORE
C
 6500 CALL KYBD(2HMS,35,1)
      CALL KYBD(2HMS,25)
      IF((IPAR1.GE.0).AND.(IPAR1.LE.800))CALL KYBD(2HMS,31,IPAR1)
      IF((IPAR1.LT.0).OR.(IPAR1.GT.800))GO TO 6800
      IL=2H**
      CALL RWCOM(1)
      IH(6)=52525B
      IH(9)=10
      IH(10)=IT(1)
      IH(11)=IT(2)
      IH(12)=IT(3)
      IH(13)=IT(4)
      IH(14)=IT(5)
```

```
      IH(34)=2H71
      CALL KYBD(2HMS,21,ION)
      CALL KYBD(2HMS,21,ICM)
      IH(34)=2H72
      IRJ=ICM-1
      IPAR1=IPAR1+2
      DO 6700 I=IBM,IRJ
      IPAR1=IPAR1+1
 6700 CALL KYBD(2HMS,21,I)
      WRITE(1,6701)IPAR1
 6701 FORMAT(/,"NEXT DATA RECORD IS ",I4)
      CALL KYBD(2HMS,35,1)
      CALL KYBD(2HMS,15)
      GO TO 1000
 6800 WRITE(1,6801)
 6801 FORMAT(/,"ERROR-INVALID DATA RECORD")
      NMP=0
      ICOMM=12345
      GO TO 1000
C*************************************************************************
C        EXIT TO OTHER OVERLAYS
C*************************************************************************
 9001 I=1
      GO TO 9900
 9002 I=2
      GO TO 9900
 9003 I=3
      GO TO 9900
 9004 I=4
      GO TO 9900
 9005 I=5
      GO TO 9900
 9006 I=6
      GO TO 9900
 9007 I=7
      GO TO 9900
 9900 CONTINUE
      IFLAG=1
      CALL RWCOM(1)
      CALL KYBD(2HMS,38,I)
      CALL OVLD(9)
 9995 CONTINUE
      IL=2H##
      IF(ICOMM.EQ.12345)CALL RWCOM(1)
      CALL KYBD(2HBS,IBS,0)
      RETURN
      END
      END$
```

```
$Y909  T=00004 IS ON CR00103 USING 00071 BLKS R=0615

FTN4
      SUBROUTINE Y0009(INTOT,IPAR)
C***********************************************************************
C         THIS PROGRAM IS STORED UNDER $Y909
C
C***********************************************************************
C
C        PROGRAMMER:  R.J.ALLEMANG
C                     MAIL LOCATION # 72
C                     UNIVERSITY OF CINCINNATI
C                     CINCINNATI, OHIO  45221
C                     513-475-6670
C
C        REVISION DATE:  JAN 19,1980
C
C***********************************************************************
      INTEGER BLANC,STER
      DIMENSION IPAR(6),LINE(36),LINE1(35),IZ(10),INQ(6)
     1,IDIV(1),ICMMD(9),IH(1),IX1(1),IY1(1),IDX(1),IDY(1)
     2,IC1(1),IPTCM(1)
     3,A1(1),M1(1),NDD1(20),BMU(10),BNU(10),IY(1)
     4,AM(1),X1(1),IPL(41),AMU(1),ANU(1),AD(1),BD(1),Q(1)
      EQUIVALENCE (LINE(2),LINE1)
      COMMON ICOMM,MANRE,MDVA,BETA,IBLS,IT(5),ID(3),IP,NUMPT
     1,NM,ICON,NCOM,XXX(3,10),IX(3,10),IC(10),NMP,XR(3),A(2,3)
     2,O(3),IB(10),NCN(10),SF(2),XXA(2,3),YYA(2,3)
     3,FSHFT,DF,MCF,IZR,IL,IPAR1,IPAR2,IPAR3,IPAR4,IPAR5,IPAR6
     4,IFLAG,NS,NE,RMM(10),FRQ(10),ZETA(10)
      EXTERNAL HDR8,DTAD0,NMAX
      DATA ICMMD/2HK ,2HMS,2HW ,2HSP,2H/D,
     12H( ,2HD ,2HCL,2HCR/
      DATA BLANC,STER,KROL/1H ,1H*,1H@/
C***********************************************************************
C         UNIVERSITY OF CINCINATI/LEUVEN MODAL ANALYSIS PROGRAM
C
C         LEAST SQUARES STARTING VALUE PROGRAM
C***********************************************************************
      IBELL=7B
      IPAGE=15414B
      CALL SETAD(HDR8,IH,-8,0)
      ICOMM=0
      IRTN=1000
      IBS=1024
      CALL KYBD(2HBS,IBS,0)
      CALL GETI(NMAX,IBLM)
      ION=IBLM-1
      ICM=ION-1
      IBM=2
      CALL RWCOM(0)
C
C         IF INITIALIZATION IS REQUIRED, LOAD Y 91
C
      IF(ICOMM.EQ.12345)GO TO 900
  850 CALL KYBD(2HMS,38,-9,1)
      CALL OVLD(9)
  900 CONTINUE
      IF(IFLAG.NE.92)GO TO 850
C
```

```
C         NOTE!!!!!!  DATA DISC RECORDS ABOVE 810 ARE USED BY THIS PROGRAM
C
C
C         STORE MODAL INFORMATION TO DISC
C
      CALL KYBD(2HMS,35,1)
      CALL KYBD(2HMS,25)
      CALL KYBD(2HMS,31,811)
      IL=2H**
      CALL RWCOM(1)
      CALL KYBD(2HMS,21,ION)
      CALL KYBD(2HMS,21,ICM)
      IRJ=ICM-1
      DO 950 I=IBM,IRJ
  950 CALL KYBD(2HMS,21,I)
      CALL KYBD(2HMS,35,1)
      CALL KYBD(2HMS,15)
C
C         SET-UP DATA SPACE FOR STARTING VALUE PROGRAM
C
      CALL SETAD(DTAD0,Q,1024,-1)
      CALL SETAD(DTAD0,AM,2048,-1)
      CALL SETAD(DTAD0,AD,3770,-1)
      CALL SETAD(DTAD0,BD,5410,-1)
      CALL SETAD(DTAD0,X1,5492,-1)
      CALL SETAD(DTAD0,AMU,5574,-1)
      CALL SETAD(DTAD0,ANU,5654,-1)
      CALL SETAD(DTAD0,A1,0,-1)
      CALL SETAD(DTAD0,M1,256,-1)
      GO TO 1501
C*****************************************************************
C        START OF MONITOR
C*****************************************************************
 1000 WRITE(1,1010)IBELL
      MFLAG=0
 1010 FORMAT("**",A2)
      I=ISWR(177677B,0,0)
      IPAR1=-9999
      IPAR2=-9999
      IPAR3=-9999
      IPAR4=-9999
 1020 DO 1030 I=1,36
 1030 LINE(I)=2H,,
 1040 CALL TTYIN(LINE)
 1042 CALL TEST(1,IST,LOG)
      CALL KDIS(0,NS,NE,4)
      IF(IST.LT.0)GO TO 1042
      CALL CODE
      READ(LINE,1120)IL
 1120 FORMAT(A2)
      CALL CODE
      READ(LINE1,*)IPAR1,IPAR2,IPAR3,IPAR4,IPAR5,IPAR6
C*****************************************************************
C        MONITOR COMMAND TABLE
C*****************************************************************
      NCMMD=9
      DO 1138  I=1,NCMMD
      IF(IL.EQ.ICMMD(I))GO TO 1144
 1138 CONTINUE
 1139 WRITE(1,1140)
```

```
      1140 FORMAT(/,"ERROR-ILLEGAL COMMAND")
           GO TO 1000
      1144 CONTINUE
           GO TO (1500,3000,1700,1400,1630,1610,5990,2000,5000),I
C*******************************************************************
C          STARTING VALUE PROGRAM BEGINS
C*******************************************************************
C             KEYBOARD ENTRY
C********************************************************************
      1501 MFLAG=1
      1500 CONTINUE
           PI2=6.283185
C*******************************************************************
C
C          IN Y909 AND Y910, THE FOLLOWING VARIABLES ARE USED AS FOLLOWS:
C
C          MFLAG   =  FLAG FOR AUTOMATIC OR INTERACTIVE
C          ITYP    =  1  NO RESIDUAL TERMS
C          ITYP    =  2  INFLUENCE OF RESIDUAL MASS ONLY
C          ITYP    =  3  INFLUENCE OF RESIDUAL FLEXIBILITY ONLY
C          ITYP    =  4  INFLUENCE OF RESIDUAL MASS AND FLEXIBILITY
C          BETA    =  EXP. DECAY RATE OF EXP. WINDOW USED ON IMPACT DATA
C                           EXP**(-BETA*TIME)
C          SCA     =  SCALE FACTOR OF MEASUREMENTS
C          NDD     =  NUMBER OF SETS OF DATA POINTS TO BE DELETED
C                         BETWEEN NS AND NE
C          NDD1(X)=   START AND END CHANNELS OF SETS OF DATA
C                         DESCRIBED BY NDD
C          MDVA    =  0,1,2  DATA IS DISPLACEMENT, VELOCITY, ACCELERATION
C          NES     =
C          MAMU    =  MAXIMUM POSSIBLE NUMBER OF MODES IN CALCULATION
C          MAN2    =  REQUESTED NUMBER OF DEGREES OF FREEDOM
C          TOL     =
C          MAN1    =  MAXIMUM POSSIBLE NUMBER OF MODES IN CALCULATION
C          MSAMP   =
C          NN      =
C          BMU(X)  =  FINAL ARRAY OF DAMPING FACTORS
C          BNU(X)  =  FINAL ARRAY OF DAMPED NATURAL FREQUENCIES
C          MANRE   =  NUMBER OF MODES USED IN PARAMETER ESTIMATION
C          NMZ     =  DIMENSION OF GREATEST POSSIBLE MATRIX
C                            REQUESTED PLUS ONE
C          MAN3    =  ACTUAL NUMBER OF ELEMENTS IN THE LARGEST MATRIX
C          MZ      =  POSSIBLE NUMBER OF ELEMENTS IN THE LARGEST MATRIX
C          AMU(X)  =  WORKING ARRAY FOR DAMPING FACTORS
C          ANU(X)  =  WORKING ARRAY FOR DAMPED NATURAL FREQUENCIES
C          MAN4    =
C
C*******************************************************************
           NES=0
           TOL=1.E-6
           MAMU=20
           MSAMP=15
           NN=40
           DO 1561 II=1,10
           BMU(II)=0.
      1561 BNU(II)=0.
           MANRE=0
           MAN1=MAMU
           MAN2=NN
           NMZ=41
```

```
      MZ=861
      MAN3=MZ
      MANU=NN
      DO 1590 II=1,MANU
      AMU(II)=0.
 1590 ANU(II)=0.
      MAN4=NMZ
      IF(MFLAG.EQ.1)GO TO 5000
      GOTO 1000
C***********************************************************************
C          CORRELATE COMMAND
C**********************************************************************
 5000 CONTINUE
      MDVA=0
      BETA=0.0
      MSHIF=NS
      MIBS=(NE-NS)*2
      DO 5002 I=1,512
 5002 Q(I)=0.
      DO 5003 I=1,MZ
 5003 AM(I)=0.
      XNO=0.
      WRITE(1,9510)IBELL
 9510 FORMAT(/,"ENTER RANGE OF DISC RECORDS FOR CURRENT TEST:"
     1,"(N1,N2,N3)"
     2,/,10X,"N1 = STARTING RECORD"
     3,/,10X,"N2 = ENDING RECORD"
     4,/,10X,"N3 = NUMBER OF SAMPLES/MEASUREMENT (OPTIONAL)",A2)
      I=0
      READ(1,*)MBL1,MBL2,I
      I1=MBL2-MBL1
      MSAMP=180/I1+2
      IF(I.GT.MSAMP)MSAMP=I
      IF(MSAMP.GT.60)MSAMP=60
      NOSAMP=0
 5005 CALL KYBD(2HMS,31,MBL1)
      CALL KYBD(2HMS,11,0)
      IF(ISSW(11).LT.0)GO TO 5006
      CALL NIXIT(MBL1)
 5006 IF(ISSW(2).LT.0)GO TO 5120
      CALL CHKID(IT,ICIC)
      IF(IH(36).NE.IZR)GO TO 5900
      IF(ICIC.EQ.0)GO TO 5900
 5120 CALL KYBD(2H_ ,0,MSHIF)
      CALL KYBD(2HBS,MIBS,0)
      CALL KYBD(2HX),1)
      CALL KYBD(2H: ,0,30000)
      CALL KYBD(2H: ,0,30000)
      CALL KYBD(2H: ,0,30000)
      MMM=MIBS/2
 5190 CONTINUE
      CALL KYBD(2HF ,0)
 5200 CALL GETQ(0,INQ)
      DT=1. /(DF*FLOAT(INQ(1)))
      XNO=XNO+1.
      INQ(2)=IAND(INQ(2),-64)/64
      CAL=(10.**INQ(2))*FLOAT(INQ(3))/FLOAT(32767)**2
      CAL1=CAL*CAL
      DO 5250 I=1,MSAMP
      NOSAMP=NOSAMP+1
```

```
      IK=I-1
      CALL SETAD(DTADO,IY,IK,-1)
      J=0
      DO 5150 I1=1,NMZ
      DO 5150 K=1,I1
      J=J+1
 5150 AM(J)=AM(J)+CAL1*(FLOAT(IY(I1))*FLOAT(IY(K)))
 5250 CONTINUE
      CALL KYBD(2HF ,0)
      CALL KYBD(2H*-,0)
      CALL KYBD(2HF ,0)
      CALL SETAD(DTADO,IY,0,-1)
      DO 5600 I=1,MIBS
 5600 Q(I)=Q(I)+FLOAT(IY(I))*CAL
 5900 CALL KYBD(2HBS,IBS,0)
      IF(MBL1.GE.MBL2)GO TO 5990
      MBL1=MBL1+1
      GO TO 5005
C*********************************************************************
C         DISPLAY COMMAND
C*********************************************************************
 5990 CALL KYBD(2HCL,0)
      CALL KYBD(2HBS,MIBS,0)
      DO 5905 I=1,MIBS
      XVAL=Q(I)
      J=I-1
 5905 CALL PUT(0,J,XVAL,YVAL)
      CALL KYBD(2HF ,0)
      CALL KYBD(2HBS,IBS,0)
      I=IBS/2-MSHIF-1
      CALL KYBD(2H_ ,0,I)
      IF(NOSAMP.LT.60)GO TO 5995
      IF(MFLAG.EQ.1)GO TO 1404
      GO TO 1000
 5995 WRITE(1,9599)
 9599 FORMAT("ERROR-NUMBER OF MEASUREMENTS INSUFFICIENT", )
      GO TO 1000
C*********************************************************************
C         PARAMETER ESTIMATION BASED ON PREVIOUSLY
C            CALCULATED MATRIX
C*********************************************************************
C            SP 0      GO TO 1402  OUTPUT ERROR FOR
C                      ALL DEGREES OF FREEDOM
C                      OR DEGREES OF FREEDOM N1 TO N2
C*********************************************************************
 1400 CONTINUE
      IF(IPAR1.EQ.-9999)IPAR1=0
      IF(IPAR1.EQ.0)GO TO 1402
      L1=IPAR1
      L2=IPAR1
      GO TO 1403
 1402 WRITE(1,9401)
 9401 FORMAT(" ENTER RANGE OF DEGREES OF FREEDOM TO BE ",
     1"USED IN PARAMETER",/,"      ESTIMATION:",/)
      READ(1,*)L1,L2
      GO TO 1403
 1404 L1=2
      L2=32
      IPAR1=0
 1403 WRITE(1,9404)IPAGE
```

```
 9404 FORMAT(A2)
C
C          DO LOOP FOR ERROR CALCULATION
C
C          SETTING MATRIX DATA (AM) INTO WORKING ARRAY (AD)
C
      DO 1480 MAN2=L1,L2
 1406 DO 1417 I=1,MZ
 1417 AD(I)=AM(I)
      GO TO 1407
 1407 MAN3=(MAN2*MAN2+MAN2)/2
      MANU=MAN2
      IF(ISSW(15).LT.0)WRITE(1,9415)AD
 9415 FORMAT(5E14.5)
      MAN4=MAN2+1
      DO 1409 I=1,MAN2
      L=MAN3+I
 1409 BD(I)=-AD(L)
C*************************************************************************
C          STEL PERFORMS GAUSSIAN REDUCTION OF MATRIX
C***********************************************************************
      CALL STEL(MAN2,IER,AD(1),BD(1),X1(1))
      IF(IER.LT.0) GO TO 1498
      DO 1408 I=1,MAN2
 1408 X1(I)=BD(1)
      X1(MAN4)=1.
      ERROR=0.
      DO 1435 I=1,MAN4
      L=MAN3+I
 1435 ERROR=ERROR-X1(I)*AM(L)
      ERROR=ABS(ERROR)
      SR=ERROR/AM(1)
C
C          PLOT ERROR IN * FORMAT
C
      DO 1436 I=2,41
1436  IPL(I)=BLANC
      IPL(1)=KROL
      IPL(41)=KROL
      SI=ALOGT(SR)*4.
      IK=IFIX(39.5+SI )
      IF(IK.GT.40)IK=40
      IF(IK.LE.2)IK=2
      DO 1437 I=2,IK
 1437 IPL(I)=STER
      CALL IOSW(NU,0)
 1480 WRITE(NU,9430)MAN2,SR,(IPL(I),I=1,41)
 9430 FORMAT("DOF",I3,"  ERROR = ",E14.6," ",41A1)
      IF(IPAR1.EQ.0)GO TO 1000
C************************************************************************
C          SP N1   COMMAND
C
C           CALCULATE FREQUENCY, DAMPING, AND ERROR
C                FOR N1 DEGREES OF FREEDOM
C
C*************************************************************************
      MAN2=L1
      CALL NRRT(X1(1),BD(1),MAN2,AMU(1),ANU(1),IER)
      IF(IER.NE.0) GO TO 1499
      DO 1430 I=1,MAN2
```

```
      SM=SC/SG
      DRL=DRL-(SJ+SK)*AU(J)-(SL-SM)*AV(J)
      DAM=DAM-(SM+SL)*AU(J)-(SK-SJ)*AV(J)
 8230 CONTINUE
      IF(IFL1.EQ.1)GO TO 8099
      IF(ITYP.EQ.1)GO TO 8100
      IF((ITYP.NE.2).AND.(ITYP.NE.4))GO TO 8200
      SA = -OM*OM + BETA*BETA
      SB = 2.*BETA*OM
      SC = SA*SA + SB*SB
      DRL = DRL + AMASS*SA/SC
      DAM = DAM + AMASS*SB/SC
 8200 IF((ITYP.NE.3).AND.(ITYP.NE.4))GO TO 8100
      DRL = DRL + AFLEX
 8099 SA=SCA*(OM**MDVA)
      IF(MDVA.EQ.2)SA=-SA
      DRL=DRL*SA
      DAM=DAM*SA
 8100 CONTINUE
      IF(JZZ.NE.INC1)GO TO 8101
      CALL GET(2,I,ARX,AIX)
      XSX=ARX-DRL
      YSY=AIX-DAM
 8101 CALL PUT(3,I,DRL,DAM)
      CALL GET(2,I,AR,AI)
 8060 SOM = SOM+(AR-DRL)**2 + (AI-DAM)**2
      IF(IFL1.NE.1)GO TO 8065
      DO 8063 I=1,NPOIN
      CALL GET(3,I,DRL,DAM)
      DRL=DRL+XSX
      DAM=DAM+YSY
      CALL PUT(3,I,DRL,DAM)
 8063 CONTINUE
 8065 CONTINUE
      WRITE(1,8999)IBELL,SOM
 8999 FORMAT(" LEAST SQUARED ERROR = ",A2,E14.5)
C***********************************************************************
C         END OF BENA3 SUBROUTINE
C***********************************************************************
      IPAR1=1
      IPAR2=NPOIN
      IF(IFL1.EQ.1)IPAR1=INC2-20
      IF(IFL1.EQ.1)IPAR2=INC2+20
      M=2
      N=3
      GO TO 8322
C************************************************************************
C          DISPLAY
C***********************************************************************
 2000 IF(IPAR2.LT.4)M=IPAR1
      IF(IPAR2.LT.4)N=IPAR2
      IFL1=1
 8322 CALL KYBD(2HY ,117)
      CALL KYBD(2HY ,117,M,0)
      CALL KYBD(2HY ,117,N,M)
      CALL KYBD(2HY ,117,M,N)
      CALL KYBD(2HY ,117,0,M)
 8321 DO 6773 I=1,36
 6773 LINE(I)=2H,,
 6759 CALL TTYIN(LINE)
```

```
      IF((INC2.LT.1).OR.(INC2.GT.255))INC2=1
 6757 CALL KDIS(M,IPAR1,IPAR2,4)
      CALL KDIS(N,IPAR1,IPAR2,4)
      DO 6745 I=1,5
 6745 CALL KDIS(N,INC2,INC2,4)
      CALL TEST(1,ISTST,LOGX1)
      IF(ISTST)6757,6758,6758
 6758 IPAR2=9999
      CALL CODE
      READ(LINE,*)IPAR1,IPAR2
C
C        IPAR1 = 0    NO MODAL COEFFICIENTS ARE STORED
C        IPAR1 < 0    STORE MODAL COEFFICIENTS
C        IPAR1 > 0    DISPLAY POINTS IPAR1 TO IPAR2
C                     IF IPAR2 IS DEFAULTED, ADD MODE
C                     IPAR1 TO RECONSTRUCTION
C
      IFL1=0
      IF(IPAR1)5060,6780,6790
 6780 IPARR=0
      CALL KYBD(2HBS,IBS,0)
      GO TO 5999
 6790 CONTINUE
      IF(IPAR2.NE.9999)GO TO 8321
      IFL1=1
      IDMODE=IPAR1
      IF(IPAR1.GT.(MANRE+1))IPAR2=NPOIN
      IF(IPAR1.GT.(MANRE+1))GO TO 8321
      IF(IPAR1.EQ.(MANRE+1))IFL1=0
      GO TO 1500
C*********************************************************************
C      STORE MODAL COEFFICIENTS
C*********************************************************************
 5060 CONTINUE
      IFL1=0
      CALL IOSW(NU,0)
      DO 5250 I=1,MANRE
      ANG=ATAN2(AV(I),AU(I))
      R=ABS(SQRT(AU(I)**2+AV(I)**2)/BMU(I))
      IF(RH(3).GT.0.0)R=R*RH(3)
      IF(RH(3).GT.0.0)AMASS=AMASS*RH(3)
      IF(RH(3).GT.0.0)AFLEX=AFLEX*RH(3)
 5140 CALL KYBD(2HBS,IBS,0)
      IF(ANG.GE.0)GO TO 5143
      R=-1.*R
      ANG=ANG+PI2/2.0
 5143 L1=IFIX(ANG*57.295779)
      IF(I.GT.NM)GO TO 5250
      RMAX=RMM(I)
      IF((ID1.EQ.2HX-).OR.(ID1.EQ.2H-1)) GO TO 5160
      IF((ID1.EQ.2HX ).OR.(ID1.EQ.2H1 ))GO TO 5170
      IF((ID1.EQ.2HY-).OR.(ID1.EQ.2H-2))GO TO 5180
      IF((ID1.EQ.2HY ).OR.(ID1.EQ.2H2 ))GO TO 5111
      IF((ID1.EQ.2HZ-).OR.(ID1.EQ.2H-3))GO TO 5500
      IF((ID1.EQ.2HZ ).OR.(ID1.EQ.2H3 ))GO TO 5210
C
C        DIRECTIONAL COSINE CHECK
C
      IF(ISSW(12))5144,5149
 5144 CONTINUE
```

```
      IF(ID1.NE.2HD )GO TO 5149
      DO 5145  IM=1,3
      IM3=IM+3
      R1=R*COS(RH(IM3)*PI2/360.0)
      CALL RWCMC(IM,R1,L1,I,IS,IP,IBM,RMAX,0)
 5145 CONTINUE
      GO TO 5515
 5149 CONTINUE
      WRITE(1,5150)
 5150 FORMAT(/,"ERROR-WRONG COORDINATE CODE")
      GO TO 5999
 5160 R=-R
 5170 CALL RWCMC(1,R,L1,I,IS,IP,IBM,RMAX,0)
      GO TO 5515
 5180 R=-R
 5111 CALL RWCMC(2,R,L1,I,IS,IP,IBM,RMAX,0)
      GO TO 5515
 5500 R=-R
 5210 CALL RWCMC(3,R,L1,I,IS,IP,IBM,RMAX,0)
 5515 CALL KYBD(2HBS,IBS,0)
      RMM(I)=RMAX
      IF(ISSW(2))7100,7200
 7100 CONTINUE
      CALL IOSW(NU,0)
      IF(I.EQ.1)WRITE(NU,7300)IS,ID1
 7300 FORMAT(/,"POINT NUMBER                = ",I4
     1,/,"DIRECTION                   = ",A2,/)
      IF(I.EQ.1)WRITE(NU,9173)AMASS,AFLEX
      IF(I.EQ.1)WRITE(NU,7005)
 7005 FORMAT(/,"MODE",8X,"FREQUENCY",4X,"ZETA(%)",4X,"MAGNITUDE"
     1,6X,"PHASE"/)
      WRITE(NU,7105)I,FRQ(I),ZETA(I),R,L1
 7105 FORMAT(1X,I4,4X,F10.3,4X,F9.6,3X,G12.6,4X,I5)
 7200 CONTINUE
 5250 CONTINUE
 5999 IF(MBL1.EQ.MBL2.AND.MFLAG.EQ.0)GO TO 1000
      IF(MBL1.EQ.MBL2.AND.MFLAG.EQ.1)GO TO 9003
      MBL1=MBL1+1
      GO TO 5005
C**********************************************************************
C          MASS STORE COMMAND
C*********************************************************************
 3000 CALL KYBD(2HMS,IPAR1,IPAR2)
      GO TO 1000
C*********************************************************************
C        REPLACE COMMAND
C*********************************************************************
 3500 CONTINUE
      DO 3600 I=1,MANRE
      FRQ(I)=BNU(I)/PI2
      NCN(I)=BNU(I)/(DF*PI2)-FSHFT/DF+1.0
      IB(I)=-1.0*BMU(I)/(DF*PI2)
      ZETA(I)=(-1.0)*BMU(I)*100.0/(SQRT(BMU(I)**2+BNU(I)**2))
 3600 CONTINUE
      GO TO 1000
C
C        RETURN TO MONITOR
C
 9001 CONTINUE
C
```

```
C         EXIT TO $Y901
C
          IFLAG=1
          CALL RWCOM(1)
          CALL KYBD(2HMS,38,-10,1)
          CALL OVLD(9)
 9003     CONTINUE
C         EXIT TO $Y903
C
          IFLAG=97
          CALL RWCOM(1)
          CALL KYBD(2HMS,38,-8,1)
          CALL OVLD(9)
 9995     CONTINUE
          IL=2H$$
          IF(ICOMM.EQ.12345)CALL RWCOM(1)
          CALL KYBD(2HBS,IBS,0)
          RETURN
          END
          END$
```

```
$Y911  T=00004 IS ON CR00103 USING 00049 BLKS R=0402

FTN4
      SUBROUTINE Y0009(INTOT,IPAR)
C**********************************************************************
C         THIS PROGRAM IS STORED UNDER $Y911
C**********************************************************************
C
C        PROGRAMMER:  R.J.ALLEMANG
C                     MAIL LOCATION # 72
C                     UNIVERSITY OF CINCINNATI
C                     CINCINNATI, OHIO  45221
C                     513-475-6670
C
C        REVISION DATE:  JAN 03, 1980
C
C**********************************************************************
      DIMENSION IPAR(6),LINE(36),LINE1(35),IZ(10),INQ(6)
     1,IDIV(1),ICMMD(24),IH(1),IX1(1),IY1(1),IDX(1),IDY(1)
     2,IC1(1),IPTCM(1),JDIR(3),JCOMP(10),JPT(250)
      EQUIVALENCE (LINE(2),LINE1)
      COMMON ICOMM,MANRE,MDVA,BETA,IBLS,IT(5),ID(3),IP,NUMPT
     1,NM,ICON,NCOM,XXX(3,10),IX(3,10),IC(10),NMP,XR(3),A(2,3)
     2,O(3),IB(10),NCN(10),SF(2),XXA(2,3),YYA(2,3)
     3,FSHFT,DF,MCF,IZR,IL,IPAR1,IPAR2,IPAR3,IPAR4,IPAR5,IPAR6
     4,IFLAG,NS,NE,RMM(10),FRQ(10),ZETA(10)
      EXTERNAL HDR8,DTAD0,NMAX
      DATA ICMMD/2HD ,2HV ,2H% ,2HEX,2H: ,
     12HM ,2H_ ,2HRO,2HA-,2HAM,
     22HCH,2HSP,2HX(,
     32HX),2HCV,2H( ,2HB ,2HL ,
     42HW ,2HI ,2HK ,2HA+,2H/L,
     52HX /
C**********************************************************************
C        UNIVERSITY OF CINCINNATI/LEUVEN MODAL ANALYSIS PROGRAM
C
C        MODE MANIPULATION PROGRAM
C**********************************************************************
      IBELL=7B
      IPAGE=15414B
      CALL SETAD(HDR8,IH,-8,0)
      ICOMM=0
      IBS=1024
      CALL KYBD(2HBS,IBS,0)
      CALL GETI(NMAX,IBLM)
      ION=IBLM-1
      ICM=ION-1
      IBM=2
      DTR=6.283185/360.0
      I=ION*IBS+270
      CALL SETAD(DTAD0,IPTCM,I,-1)
      CALL RWCOM(0)
      IF(ICOMM.EQ.12345)GO TO 900
      CALL KYBD(2HMS,38,-2,1)
      CALL OVLD(9)
 900  CONTINUE
      IF(IFLAG.EQ.1)GO TO 1130
C**********************************************************************
C       START OF MONITOR
C**********************************************************************
```

```
 1000 WRITE(1,1010)IBELL
 1010 FORMAT("*",A2)
      I=ISWR(177677B,0,0)
      IPAR1=-9999
      IPAR2=-9999
      IPAR3=-9999
      IPAR4=-9999
      IPAR5=-9999
      IPAR6=-9999
 1020 DO 1030 I=1,36
 1030 LINE(I)=2H,,
 1040 CALL TTYIN(LINE)
 1042 CALL TEST(1,IST,LOG)
      IF(IST.LT.0)GO TO 1042
      CALL CODE
      READ(LINE,1120)IL
 1120 FORMAT(A2)
      CALL CODE
      READ(LINE1,*)IPAR1,IPAR2,IPAR3,IPAR4,IPAR5,IPAR6
C**********************************************************************
C      MONITOR COMMAND TABLE
C**********************************************************************
 1130 IFLAG=0
      CALL RWCOM(1)
      IF(IL.EQ.2H##)GO TO 1000
      NCMMD=24
      DO 1138  I=1,NCMMD
      IF(IL.EQ.ICMMD(I))GO TO 1144
 1138 CONTINUE
 1139 WRITE(1,1140)
 1140 FORMAT(/,"ERROR-ILLEGAL COMMAND")
      GO TO 1000
 1144 IF(I.GT.10)GO TO 1146
      GO TO (9004,9004,9004,9004,9004,9004,9004,9004,9004,9004),I
 1146 I=I-10
      IF(I.GT.10)GO TO 1148
      GO TO (9004,9004,6000,6500,9004,9995,1100,1100,9002,9001),I
 1148 I=I-10
      GO TO (9001,9003,9008,2000),1
 1100 CONTINUE
      IF(IPAR1.EQ.37)GO TO 9005
      IF(IPAR1.EQ.10)GO TO 9006
      IF(IPAR1.EQ.6)GO TO 9007
      GO TO 1139
C**********************************************************************
C          CALCULATE MODAL ASSURANCE CRITERION BETWEEN SHAPEVECTORS
C**********************************************************************
 2000 CONTINUE
      IF(IPAR1.EQ.1)GO TO 4000
      IF(IPAR1.EQ.2)GO TO 8000
      DO 2010 I=1,3
 2010 JDIR(I)=I
      DO 2020 I=1,10
 2020 JCOMP(I)=I
      DO 2030 I=1,250
 2030 JPT(I)=I
 2040 CONTINUE
      WRITE(1,2050)IPAGE,IBELL
 2050 FORMAT(A2,/,"ENTER OPTION FOR MODAL ASSURANCE CRITERIA: "
     1,/,10X,"1) MEASUREMENT DIRECTION"
```

```
     2,/,10X,"2) COMPONENTS"
     3,/,10X,"3) POINT NUMBERS"
     4,/,10X,"4) CONTINUE"
     5,/,10X,"5) RETURN TO MONITOR",A2)
      READ(1,*)IANS
      GO TO (2100,2200,2300,2400,1000)IANS
 2100 CONTINUE
      DO 2110 I=1,3
 2110 JDIR(I)=0
 2120 CONTINUE
      N1=-9999
      N2=-9999
      WRITE(1,2140)IBELL
 2140 FORMAT(A2,/,"DIRECTION(S)?")
      READ(1,*)N1,N2
      IF(N1.LE.0)GO TO 2040
      IF(N1.GT.3)GO TO 2120
      IF((N2.LE.0).OR.(N2.GT.3))N2=N1
      DO 2150 I=N1,N2
 2150 JDIR(I)=I
      GO TO 2120
 2200 CONTINUE
      DO 2210 I=1,10
 2210 JCOMP(I)=0
 2220 CONTINUE
      N1=-9999
      N2=-9999
      WRITE(1,2240)IBELL
 2240 FORMAT(A2,/,"COMPONENT(S)?")
      READ(1,*)N1,N2
      IF(N1.LE.0)GO TO 2040
      IF(N1.GT.10)GO TO 2220
      IF((N2.LE.0).OR.(N2.GT.10))N2=N1
      DO 2250 I=N1,N2
 2250 JCOMP(I)=I
      GO TO 2220
 2300 CONTINUE
      DO 2310 I=1,250
 2310 JPT(I)=0
 2320 CONTINUE
      N1=-9999
      N2=-9999
      WRITE(1,2340)IBELL
 2340 FORMAT(A2,/,"POINT NUMBER(S)?")
      READ(1,*)N1,N2
      IF(N1.LE.0)GO TO 2040
      IF(N1.GT.250)GO TO 2320
      IF((N2.LE.0).OR.(N2.GT.250))N2=N1
      DO 2350 I=N1,N2
 2350 JPT(I)=I
      GO TO 2320
 2400 CONTINUE
      WRITE(1,2410)IBELL
 2410 FORMAT(A2,/,"ENTER REFERENCE MODE NUMBER:")
      READ(1,*)IMODE
      WRITE(1,2420)IBELL
 2420 FORMAT(A2,/,"ENTER ANALYSIS MODE NUMBER:")
      READ(1,*)JMODE
      WRITE(1,2430)IBELL
 2430 FORMAT(A2,/,"ENTER METHOD TO BE USED TO CALCULATE 'MAC':"
```

```
     1,/,10X,"1) COMPLEX SHAPEVECTOR"
     2,/,10X,"2) REAL SHAPEVECTOR",/)
      READ(1,*)MAC
      IF((MAC.NE.1).AND.(MAC.NE.2))MAC=1
      AM1=0.0
      AM2=0.0
      CMR=0.0
      CMI=0.0
      DO 3000 I=1,IP
      IF(JPT(I).EQ.0)GO TO 3000
      K=IPTCM(I)
      IF(JCOMP(K).EQ.0)GO TO 3000
      DO 2900 J=1,3
      IF(JDIR(J).EQ.0)GO TO 2900
      IF(ISSW(14).LT.0)GO TO 1000
      RMAX1=RMM(IMODE)
      RMAX2=RMM(JMODE)
      CALL RWCMC(J,R1,L1,IMODE,I,IP,IBM,RMAX1,1)
      CALL RWCMC(J,R2,L2,JMODE,I,IP,IBM,RMAX2,1)
      IF(MAC.EQ.2)L1=90
      IF(MAC.EQ.2)L2=90
      AR1=R1*COS(FLOAT(L1)*DTR)
      AR2=R2*COS(FLOAT(L2)*DTR)
      AI1=R1*SIN(FLOAT(L1)*DTR)
      AI2=R2*SIN(FLOAT(L2)*DTR)
      AM1=AR1*AR1+AI1*AI1+AM1
      AM2=AR2*AR2+AI2*AI2+AM2
      CMR=AR2*AR1+AI2*AI1+CMR
      CMI=AR1*AI2-AR2*AI1+CMI
 2900 CONTINUE
 3000 CONTINUE
      AMAC=(CMR*CMR+CMI*CMI)/(AM1*AM2)
      SFR=CMR/AM1
      SFI=CMI/AM1
      CALL IOSW(NU,0)
      WRITE(NU,3100)AMAC,SFR,SFI
 3100 FORMAT(/,"MODAL ASSURANCE CRITERION.....",10X,F10.7
     1,/,"MODAL SCALE FACTOR(REAL)......",4X,F16.7
     2,/,"MODAL SCALE FACTOR(IMAG)......",4X,F16.7)
      GO TO 1000
C*************************************************************************
C        MODE SCALE
C*************************************************************************
 4000 CONTINUE
      WRITE(1,4020)IBELL
 4020 FORMAT(A2,/,"ENTER ANALYSIS MODE NUMBER?")
      READ(1,*)IMODE
      WRITE(1,4030)IBELL
 4030 FORMAT(A2,/,"ENTER DESTINATION MODE NUMBER?")
      READ(1,*)KMODE
      IF(IMODE.EQ.KMODE)GO TO 4000
      IF(IPAR2.NE.-9999)GO TO 4050
      WRITE(1,4040)IBELL
 4040 FORMAT(A2,/,"ENTER MODAL SCALE FACTOR")
      SFR=0.0
      SFI=0.0
      READ(1,*)SFR,SFI
 4050 CONTINUE
      RMAX3=0.0
      DO 5000 I=1,IP
```

```
      DO 4900 J=1,3
      IF(ISSW(14).LT.0)GO TO 1000
      RMAX1=RMM(IMODE)
      CALL RWCMC(J,R1,L1,IMODE,I,IP,IBM,RMAX1,1)
      AR1=R1*COS(FLOAT(L1)*DTR)
      AI1=R1*SIN(FLOAT(L1)*DTR)
      AR3=(AR1*SFR+AI1*SFI)
      AI3=(AI1*SFR-AR1*SFI)
      SFF=SFR*SFR+SFI*SFI
      AR3=AR3/SFF
      AI3=AI3/SFF
      R3=SQRT(AR3*AR3+AI3*AI3)
      ANG=ATAN2(AI3,AR3)
      L3=ANG/DTR
      IF(L3.GE.0)GO TO 4500
      R3=(-1.0)*R3
      L3=L3+180
 4500 CONTINUE
      CALL RWCMC(J,R3,L3,KMODE,I,IP,IBM,RMAX3,0)
 4900 CONTINUE
 5000 CONTINUE
      RMM(KMODE)=RMAX3
      FRQ(KMODE)=FRQ(IMODE)
      ZETA(KMODE)=ZETA(IMODE)
      NCN(KMODE)=NCN(IMODE)
      IB(KMODE)=IB(IMODE)
      GO TO 1000
C*********************************************************************
C         MODE SUBTRACTION
C*********************************************************************
 8000 CONTINUE
      WRITE(1,8010)IBELL
 8010 FORMAT(A2,/,"ENTER REFERENCE MODE NUMBER?")
      READ(1,*)IMODE
      WRITE(1,8020)IBELL
 8020 FORMAT(A2,/,"ENTER ANALYSIS MODE NUMBER?")
      READ(1,*)JMODE
      WRITE(1,8030)IBELL
 8030 FORMAT(A2,/,"DESTINATION MODE NUMBER?")
      READ(1,*)KMODE
      IF(IMODE.EQ.KMODE)GO TO 8000
      IF(JMODE.EQ.KMODE)GO TO 8000
      RMAX3=0.0
      DO 8990 I=1,IP
      DO 8900 J=1,3
      IF(ISSW(14).LT.0)GO TO 1000
      RMAX1=RMM(IMODE)
      RMAX2=RMM(JMODE)
      CALL RWCMC(J,R1,L1,IMODE,I,IP,IBM,RMAX1,1)
      CALL RWCMC(J,R2,L2,JMODE,I,IP,IBM,RMAX2,1)
      AR1=R1*COS(FLOAT(L1)*DTR)
      AR2=R2*COS(FLOAT(L2)*DTR)
      AI1=R1*SIN(FLOAT(L1)*DTR)
      AI2=R2*SIN(FLOAT(L2)*DTR)
      AR3=AR2-AR1
      AI3=AI2-AI1
      R3=SQRT(AR3*AR3+AI3*AI3)
      ANG=ATAN2(AI3,AR3)
      L3=ANG/DTR
      IF(L3.GE.0)GO TO 8500
```

```
      R3=(-1.0)*R3
      L3=L3+180
 8500 CONTINUE
      CALL RWCMC(J,R3,L3,KMODE,I,IP,IBM,RMAX3,0)
 8900 CONTINUE
 8990 CONTINUE
      RMM(KMODE)=RMAX3
      FRQ(KMODE)=FRQ(JMODE)
      ZETA(KMODE)=ZETA(JMODE)
      NCN(KMODE)=NCN(JMODE)
      IB(KMODE)=IB(JMODE)
      GO TO 1000
C
C       STORE AND READ SET-UP AND MODAL DATA TO AND FROM DISC
C
C         READ
C
 6000 CALL KYBD(2HMS,35,1)
      CALL KYBD(2HMS,25)
      IF(IPAR1.EQ.-9999)GO TO 7000
      IF((IPAR1.GE.0).AND.(IPAR1.LE.800)) CALL KYBD(2HMS,31,IPAR1)
      IF((IPAR1.LT.0).OR.(IPAR1.GT.800))GO TO 6800
      CALL KYBD(2HMS,11,0)
      CALL KYBD(2HMS,31,-1,1)
      CALL RWCOM(-1)
      IF(ICOMM.NE.12345)GO TO 6800
      CALL KYBD(2HMS,11,ION)
      CALL RWCOM(0)
      IF(ICOMM.NE.12345)GO TO 6800
      NMP=0
      IRJ=ICM
      CALL KYBD(2HMS,11,IRJ)
      IRJ=IRJ-1
 6100 DO 6200 I=IBM,IRJ
 6200 CALL KYBD(2HMS,11,I)
      CALL KYBD(2HMS,35,1)
      CALL KYBD(2HMS,15)
      ICOMM=12345
      WRITE(1,1235)(IT(I),I=1,5)
 1235 FORMAT(/,"TEST ID IS",23X,5A2)
      GO TO 1000
C
C         STORE
C
 6500 CALL KYBD(2HMS,35,1)
      CALL KYBD(2HMS,25)
      IF(IPAR1.EQ.-9999)GO TO 7500
      IF((IPAR1.GE.0).AND.(IPAR1.LE.800))CALL KYBD(2HMS,31,IPAR1)
      IF((IPAR1.LT.0).OR.(IPAR1.GT.800))GO TO 6800
      IL=2H**
      CALL RWCOM(1)
      IH(6)=52525B
      IH(9)=10
      IH(10)=IT(1)
      IH(11)=IT(2)
      IH(12)=IT(3)
      IH(13)=IT(4)
      IH(14)=IT(5)
      IH(34)=2H71
      CALL KYBD(2HMS,21,ION)
```

```
      CALL KYBD(2HMS,21,ICM)
      IH(34)=2H72
      IRJ=ICM-1
      IPAR1=IPAR1+2
      DO 6700 I=IBM,IRJ
      IPAR1=IPAR1+1
 6700 CALL KYBD(2HMS,21,I)
      WRITE(1,6701)IPAR1
 6701 FORMAT(/,"NEXT DATA RECORD IS ",I4)
      CALL KYBD(2HMS,35,1)
      CALL KYBD(2HMS,15)
      GO TO 1000
 6800 WRITE(1,6801)
 6801 FORMAT(/,"ERROR-INVALID DATA RECORD")
      NMP=0
      ICOMM=12345
      GO TO 1000
C
C          LOAD MODE SHAPEVECTOR
C
 7000 CONTINUE
      WRITE(1,7001)IBELL
 7001 FORMAT(A2,/,"SOURCE MODE NUMBER?")
      READ(1,*)IMODE
      RMAX=RMM(IMODE)
      DO 7100 I=1,IP
      CALL RWCMC(1,R,L1,IMODE,I,IP,IBM,RMAX,1)
      CALL RWCMC(1,R,L1,1,I,IP,1,RMAX,0)
      CALL RWCMC(2,R,L1,IMODE,I,IP,IBM,RMAX,1)
      CALL RWCMC(2,R,L1,1,I,IP,1,RMAX,0)
      CALL RWCMC(3,R,L1,IMODE,I,IP,IBM,RMAX,1)
      CALL RWCMC(3,R,L1,1,I,IP,1,RMAX,0)
 7100 CONTINUE
      IBW=IB(IMODE)
      ICHAN=NCN(IMODE)
      FREQ=FRQ(IMODE)
      DAMP=ZETA(IMODE)
      MAXPT=IP
      GO TO 1000
C
C          STORE MODE SHAPEVECTOR
C
 7500 CONTINUE
      WRITE(1,7501)IBELL
 7501 FORMAT(A2,/,"TARGET MODE NUMBER?")
      READ(1,*)IMODE
      IF(IMODE.GT.NM)GO TO 7500
      IF(IP.GT.MAXPT)GO TO 7900
      RMM(IMODE)=RMAX
      IB(IMODE)=IBW
      NCN(IMODE)=ICHAN
      FRQ(IMODE)=FREQ
      ZETA(IMODE)=DAMP
      DO 7600 I=1,IP
      CALL RWCMC(1,R,L1,1,I,IP,1,RMAX,1)
      CALL RWCMC(1,R,L1,IMODE,I,IP,IBM,RMAX,0)
      CALL RWCMC(2,R,L1,1,I,IP,1,RMAX,1)
      CALL RWCMC(2,R,L1,IMODE,I,IP,IBM,RMAX,0)
      CALL RWCMC(3,R,L1,1,I,IP,1,RMAX,1)
      CALL RWCMC(3,R,L1,IMODE,I,IP,IBM,RMAX,0)
```

```
 7600 CONTINUE
      GO TO 1000
 7900 CONTINUE
      WRITE(1,7901)IBELL
 7901 FORMAT(A2,/,"ERROR-ILLEGAL VECTOR LENGTH")
      GO TO 1000
 ***********************************************************************
C          EXIT TO OTHER OVERLAYS
C***********************************************************************
 9001 I=1
      GO TO 9900
 9002 I=2
      GO TO 9900
 9003 I=3
      GO TO 9900
 9004 I=4
      GO TO 9900
 9005 I=5
      GO TO 9900
 9006 I=6
      GO TO 9900
 9007 I=7
      GO TO 9900
 9008 I=8
      GO TO 9900
 9900 CONTINUE
      IFLAG=1
      CALL RWCOM(1)
      CALL KYBD(2HMS,38,I)
      CALL OVLD(9)
 9995 CONTINUE
      IL=2H**
      IF(ICOMM.EQ.12345)CALL RWCOM(1)
      CALL KYBD(2HBS,IBS,0)
      RETURN
      END
      END$
```

```
$Y900  T=00004 IS ON CR00103 USING 00019 BLKS R=0147

FTN4,L
      SUBROUTINE Y0009(INTOT,IPAR)
C
C         THIS PROGRAM IS STORED UNDER $Y900
C
C**********************************************************************
C
C        PROGRAMMER:  R.J.ALLEMANG
C                     MAIL LOCATION # 72
C                     UNIVERSITY OF CINCINNATI
C                     CINCINNATI, OHIO  45221
C                     513-475-6670
C
C        REVISION DATE:  JAN,19,1980
C
C**********************************************************************
      DIMENSION IPAR(6),LINE(36),LINE1(35),IZ(10),INQ(6)
     1,IDIV(1),ICMMD(24),IH(1),IX1(1),IY1(1),IDX(1),IDY(1)
     2,IC1(1),IPTCM(1)
      EQUIVALENCE (LINE(2),LINE1)
      COMMON ICOMM,MANRE,MDVA,BETA,IBLS,IT(5),ID(3),IP,NUMPT
     1,NM,ICON,NCOM,XXX(3,10),IX(3,10),IC(10),NMP,XR(3),A(2,3)
     2,O(3),IB(10),NCN(10),SF(2),XXA(2,3),YYA(2,3)
     3,FSHFT,DF,MCF,IZR,IL,IPAR1,IPAR2,IPAR3,IPAR4,IPAR5,IPAR6
     4,IFLAG,NS,NE,RMM(10),FRQ(10),ZETA(10)
      EXTERNAL HDRB,DTAD0,NMAX
      DATA ICMMD/2HD ,2HV ,2H% ,2HEX,2H: ,
     12HM ,2H_ ,2HRO,2HA-,2HAM,
     22HCH,2HSP,2HX<,
     32HX>,2HCV,2H< ,2HB ,2HL ,
     42HW ,2HI ,2HK ,2HA+,2H/L,
     52HX /
C**********************************************************************
C        UNIVERSITY OF CINCINNATI/LEUVEN MODAL ANALYSIS PROGRAM
C
C        DUMMY OVERLAY PROGRAM
C**********************************************************************
      IBELL=7B
      IPAGE=15414B
      CALL SETAD(HDRB,IH,-8,0)
      ICOMM=0
      IBS=1024
      CALL KYBD(2HBS,IBS,0)
      CALL GETI(NMAX,IBLM)
      ION=IBLM-1
      ICM=ION-1
      IBM=2
      I=ION*IBS+270
      CALL SETAD(DTAD0,IPTCM,I,-1)
      CALL RWCOM(0)
      WRITE(1,900)IBELL
  900 FORMAT(A2,/,"ERROR-COMMAND NOT AVAILABLE IN CONFIGURATION"
     1,/,"       OF SOFTWARE AND HARDWARE")
C**********************************************************************
C       START OF MONITOR
C**********************************************************************
 1000 WRITE(1,1010)IBELL
 1010 FORMAT("*",A2)
```

```
      I=ISWR(177677B,0,0)
      IPAR1=-9999
      IPAR2=-9999
      IPAR3=-9999
      IPAR4=-9999
      IPAR5=-9999
      IPAR6=-9999
 1020 DO 1030 I=1,36
 1030 LINE(I)=2H,,
 1040 CALL TTYIN(LINE)
 1042 CALL TEST(1,IST,LOG)
      IF(IST.LT.0)GO TO 1042
      CALL CODE
      READ(LINE,1120)IL
 1120 FORMAT(A2)
      CALL CODE
      READ(LINE1,*)IPAR1,IPAR2,IPAR3,IPAR4,IPAR5,IPAR6
C***********************************************************************
C       MONITOR COMMAND TABLE
C***********************************************************************
 1130 IFLAG=0
      CALL RWCOM(1)
      IF(IL.EQ.2H**)GO TO 1000
      NCMMD=24
      DO 1138  I=1,NCMMD
      IF(IL.EQ.ICMMD(I))GO TO 1144
 1138 CONTINUE
 1139 WRITE(1,1140)
 1140 FORMAT(/,"ERROR-ILLEGAL COMMAND")
      GO TO 1000
 1144 IF(I.GT.10)GO TO 1146
      GO TO (9004,9004,9004,9004,9004,9004,9004,9004,9004,9004),I
 1146 I=I-10
      IF(I.GT.10)GO TO 1148
      GO TO (9004,9004,9004,9004,9004,9995,1100,1100,9002,9001),I
 1148 I=I-10
      GO TO (9001,9003,9008,9011),I
 1100 CONTINUE
      IF(IPAR1.EQ.37)GO TO 9005
      IF(IPAR1.EQ.10)GO TO 9006
      IF(IPAR1.EQ.6)GO TO 9007
      GO TO 1139
C**********************************************************************
C          EXIT TO OTHER OVERLAYS
C**********************************************************************
 9001 I=1
      GO TO 9900
 9002 I=2
      GO TO 9900
 9003 I=3
      GO TO 9900
 9004 I=4
      GO TO 9900
 9005 I=5
      GO TO 9900
 9006 I=6
      GO TO 9900
 9007 I=7
      GO TO 9900
 9008 I=8
```

```
      GO TO 9900
 9011 I=11
      GO TO 9900
 9900 CONTINUE
      IFLAG=1
      CALL RWCOM(1)
      CALL KYBD(2HMS,38,I)
      CALL OVLD(9)
 9995 CONTINUE
      IL=2H##
      IF(ICOMM.EQ.12345)CALL RWCOM(1)
      CALL KYBD(2HBS,IBS,0)
      RETURN
      END
      END$
```

APPENDIX B

AIRCRAFT SOFT SUPPORT SYSTEM

1.0 SYSTEM REQUIREMENTS

An aircraft soft support system for use in ground vibration testing is a system which supports the airplane in such a manner that its elastic modes of vibration are little modified by the presence of the support. This is accomplished by supporting the airplane so that 1) its rigid body natural frequencies are sufficiently lower than the first elastic mode and the damping in these rigid body modes sufficiently low so that there is little coupling between these rigid body and elastic modes, 2) the support pickup points on the airplane are selected to minimize their effect on the significant elastic modes of the airplane, 3) the internal resonances of the support system (including the test airplane mass) are well separated from the elastic modes of interest on the test airplane and, 4) the airplane resting on the support system is sufficiently stable. In addition the support system should be sufficiently rugged and reliable to require little attention during use.

2.0 CANDIDATE APPROACHES

2.1 Low Spring Rate Component

Soft support systems usually contain a discrete low spring rate component to provide the low frequency support and avoid internal resonances. This section discusses several ways this has been accomplished.

Soft Tires - Partially deflating the tires is an expedient way to obtain a soft support. In addition there is no doubt about airplane stability, as the airplane rests on the landing gear just as it was designed to do. Soft tires have the disadvantage that the frequency separation between the rigid body and elastic modes is margional, typically 1:2 in frequency, and frequently the tires are damaged.

Air Bags - Supporting the test airplane on air bags can offer excellent frequency separation. Air bags have the disadvantage of having such low damping and low lateral stiffness that stability of the airplane becomes a problem. Often auxiliary devices must be used to compensate for this shortcoming of air bags.

Mechanical Springs - Mechanical springs can be selected which offer excellent frequency separation. Friction in the springs and the large static deflection that accompanies the low natural frequencies cause difficulties with mechanical springs.

Bungee - Bungee cord supports have been constructed that had very good frequency separation. Difficulties involved large static deflections and load distribution among the multiple bungee cords.

Airsprings - Airsprings have been used with success on a number of tests. The airsprings consist of an air chamber with a sealed platform floating on the air contained in the chamber. Self leveling feedback control devices and dampers are common components. Potential disadvantages of airsprings are limited travel and a requirement for a compressed air source. Custom fabricated airsprings were developed for use in the XB-70 GVT and are in routine use at DFVLR. The airsprings used in the A-10 test were commercially available off the shelf models.

2.2 Support Configuration

Overhead - Suspending the test airplane from an overhead support is a very attractive way to satisfy airplane stabillity requirements. Regardless of the inherent stability of the low spring rate component, pendulum stability will assure a stable system. The difficulty with this approach is that the overhead support invariably has a long load path to ground. This load path must be quite stiff to avoid internal support resonances that couple with the test airplane. Hangar walls and roofs rarely provide the required stiffness and a special overhead frame is usually required for the GVT.

Underneath - Suspending the test airplane from below rather than with an overhead suspension permits designing to avoid internal support resonances much more easily. The load paths to ground are usually very short, although care must be

taken to verifying that the hangar floor the supports rest on is reasonably rigid. On a number of unfortunate occasions the fill under the floor was found to have settled, and the floor was really hollow. Special attention must also be paid to airplane stability with an underneath suspension. The low spring rate components tend to be unstable in compression and special attention must be paid to this in designing the support system. Although easier access to the airplane has been cited as an advantage to an overhead support system, accessibility is much more affected by design details of the system than by overhead or under configuration.

3.0 A-10 TEST SOFT SUPPORT SYSTEM

3.1 System Description

The system selected for the A-10 demonstration ground vibration test of this contract included airsprings and an underneath support configuration. Three airsprings and supports were used. The airplane was supported at the aft body jacking point and at the auxiliary jacking points at either side of the fore body. This provides minimum constraint to the wing and to aft body torsion, so the coupling between the soft support system and most of the significant modes of the airplane should be low. This support configuration also provided stability. Both roll and pitch stability were insured because the fore body jacking fittings are located vertically near the c.g. and because the forebody and aft body jacking fittings are far apart.

3.1.1 Airsprings

Commercially available airsprings were used in the A-10 system. These airsprings had a mechanical servo system that kept the floating platform at a constant level. When the load on the airspring increased and the level dropped the input air valve opened and the air pressure in the airspring increased until the platform was returned to the desired level. When the load decreased and the platform level raised air was valved from the airspring by the servo to regain the desired level. The time constant in this servo system was about 10 seconds. Because this airspring is a nearly constant air volume device, the natural frequency is nearly independent of the mass it is supporting. For the airsprings

selected, the manufacturer specified a vertical natural frequency of 1.5 $\pm$ .1 Hz. The manufacturer also specified a lateral natural frequency of 2.5 Hz. The airsprings incorporated a damper.

3.1.2 Support

The supports under the airsprings were concrete blocks. The concrete blocks rested on the hangar floor. Their height was selected to facilitate installation of the airplane on the soft support system. The hangar floor at the test site had been constructed quite some time ago of very massive heavily reinforced concrete especially for test work.

3.2 Fabrication

The commercially available airsprings were delivered in less than four weeks after ordering. The concrete blocks were poured in-house in wooden forms. Note the fork lift fittings cast into the concrete blocks and the steel bed plate on top of the concrete blocks (see the photographs). New concrete blocks should probably be poured for each new airplane design tested since a different support height will usually be required and the blocks are easy to fabricate. The blocks for this test were fabricated in three days at very modest cost.

A fitting was fabricated to mate the top of the airspring to the airplane jacking fitting. Although this fitting was originally designed as a ball and socket fitting, it later had to be redesigned as a clamped fitting. This is needed because the floating plate of the airspring can transmit no moments, and in order

that the plate float level either a point load must be applied at its exact center, or a clamped fitting must be used forcing the plate to float level.

3.3 Installation

The concrete blocks were sized to permit easy installation of the airplane on the soft support system. To install the support system first the airplane's oleo struts were blown to full extension. The concrete blocks were positioned under the jack fittings and the airsprings were placed in position. The airsprings are unpressurized and bottomed. The wing jacks were set in place and the airplane was jacked from the wing jacks. The main landing gear oleo strut was depressurized and the main landing gear was retracted. The wing jacks were slowly lowered, placing the weight of the airplane on the airsprings. The nose gear oleo strut was depressurized and the nose gear was retracted.

3.4 Operating Procedure

The system worked fine with little attention required. At the end of the test day the wing jacks were set in place and the air was released from the airsprings. To start the test day the airsprings were pressurized and the wing jacks removed. About every three days the nitrogen bottle used to pressurize the system was replaced. The rate of nitrogen consumption was increased because of valving when someone would be walking on one wing (e.g. to check a troublesome accelerometer) with the suspension system active.

4.0 BOILERPLATE TEST

A boilerplate test was conducted on the airsprings to verify their operation before the GVT and to confirm the manufacturers natural frequency specifications.

Two different test rigs were used. The test rigs were assembled from standard structures laboratory "tinker toy" I beams, 2500 lb. dead weights and the airsprings. The first test rig attempted to simulate the airplane mass, inertia and jacking point locations. As first built up this rig had its center of gravity about two feet higher than the airplane's. This system was unstable in roll because the natural frequency in roll coincided with the natural frequency of the servo-leveling feedback control system. (Note that gravity acts as a negative spring in roll for this case. The effective roll spring is the airsprings minus the gravity effect. The higher the c.g. the larger is the gravity effect.) After the rig was rebuilt to get the c.g. correct there were no more stability problems. The rig was shaken to determine its modes and frequencies.

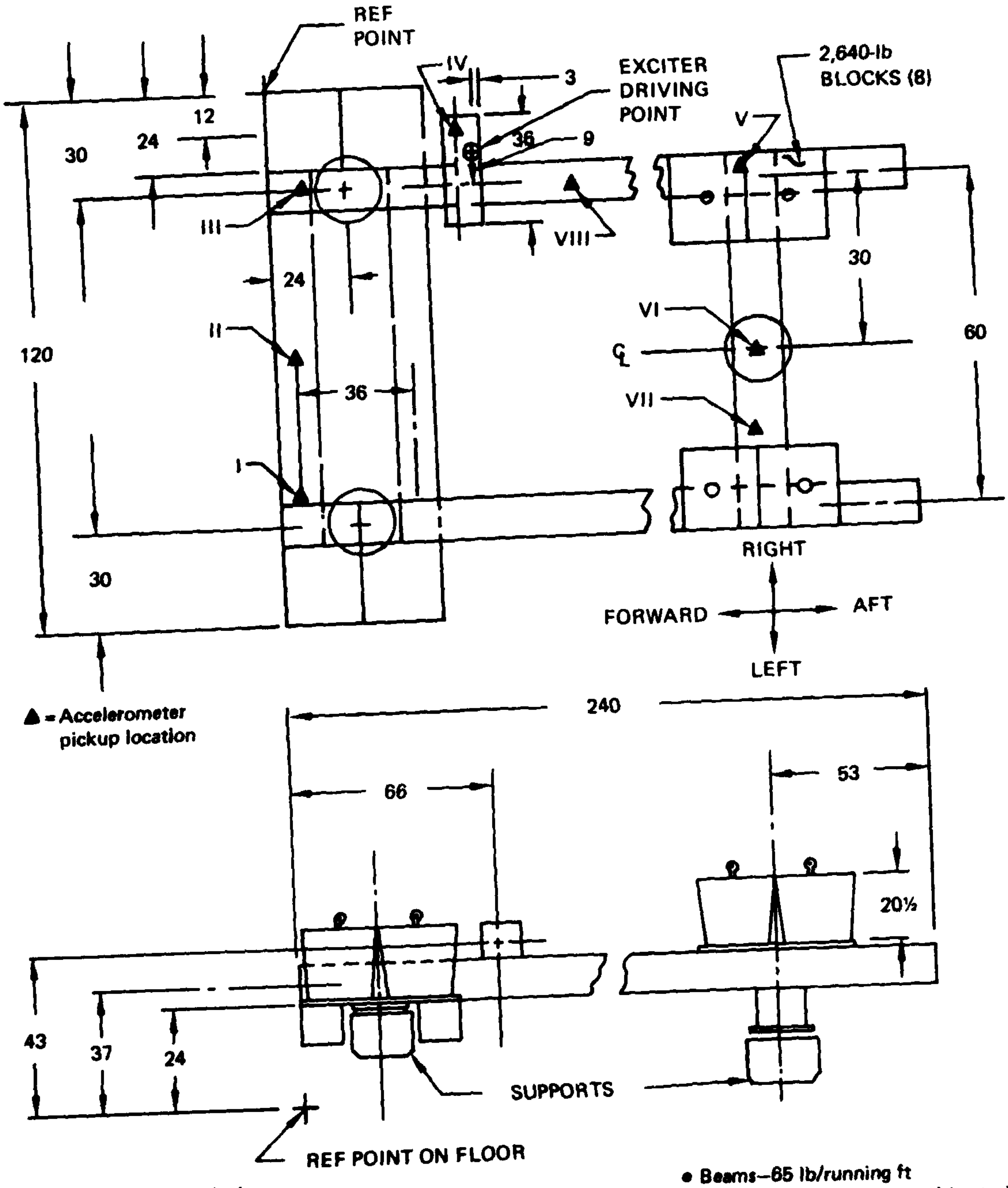
The results of this test are tabulated in Figure B-1. A sketch of this rig is included in Figure B-2. Because this rig proved undesirably flexible a second test rig was built. This rig had the long flexible elements shortened up as much as possible. The mass of the airplane was matched by the rig and the jacking point locations approximately preserved, but inertia was not matched. The rig was only shaken for the vertical translation mode, which was recorded as 1.41 Hz.

Photographs of the test rig are shown on Figures B-3 through B-8.

Frequency	Description
.5 Hz	Body roll - More rocking motion on aft pillow
1.17 Hz	Roll about logitudinal Not a clean mode
1.5 Hz	Pitching of body (frequency could be from 1.5 to 1.7 Hz.)
2.6 Hz	Forward - Aft pitching forward end with small amplitude - not in or out of phase
2.9 Hz	Body torsional - Aft shimmy lateral (frequency could be from 2.8 to 3.0 Hz.)
3.7 Hz	Forward body vertical
4.5 Hz	Right front vertical some rolling of structure with FWD-AFT movement
6.9 to 9.0 Hz	Beam bending and 2640# mass motion (rocking)

Note: The response of this structure is complex - all modes contain motion in practically every possible direction. Damping appears low - for the structure and high for the pillow supports. The supports do bottom out at low frequencies and lateral motion of only about 1/4" can exist before exceeding the units side travel.

Figure B-1. Boilerplate Test Rig No. 1 Results



• All dimensions in inches
• Not to scale

• Beams—65 lb/running ft
• Bed plates under weights—1-in steel

Figure B-2. A-10 Air-Spring Suspension

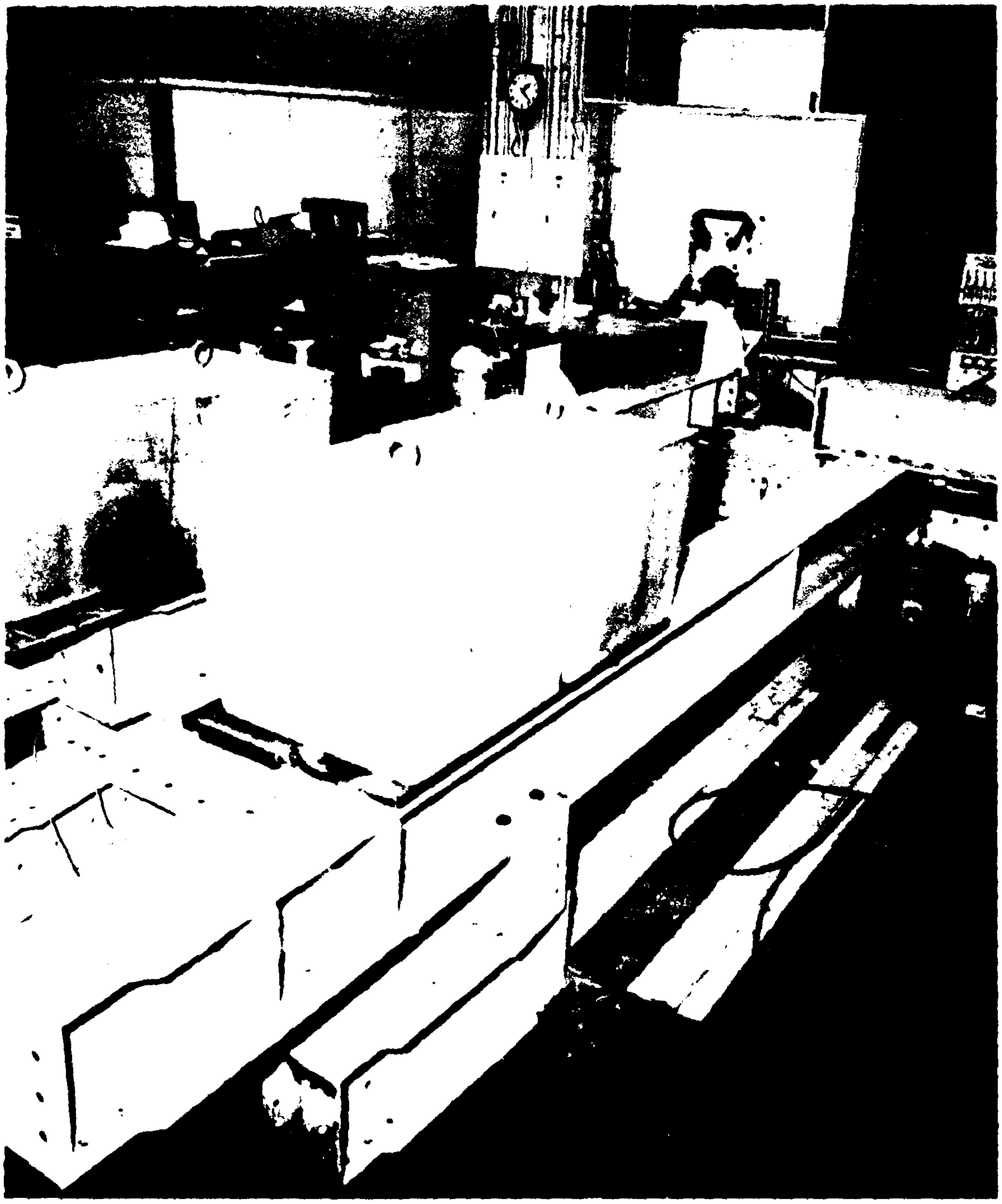


Figure B-3. Boilerplate Test Rig

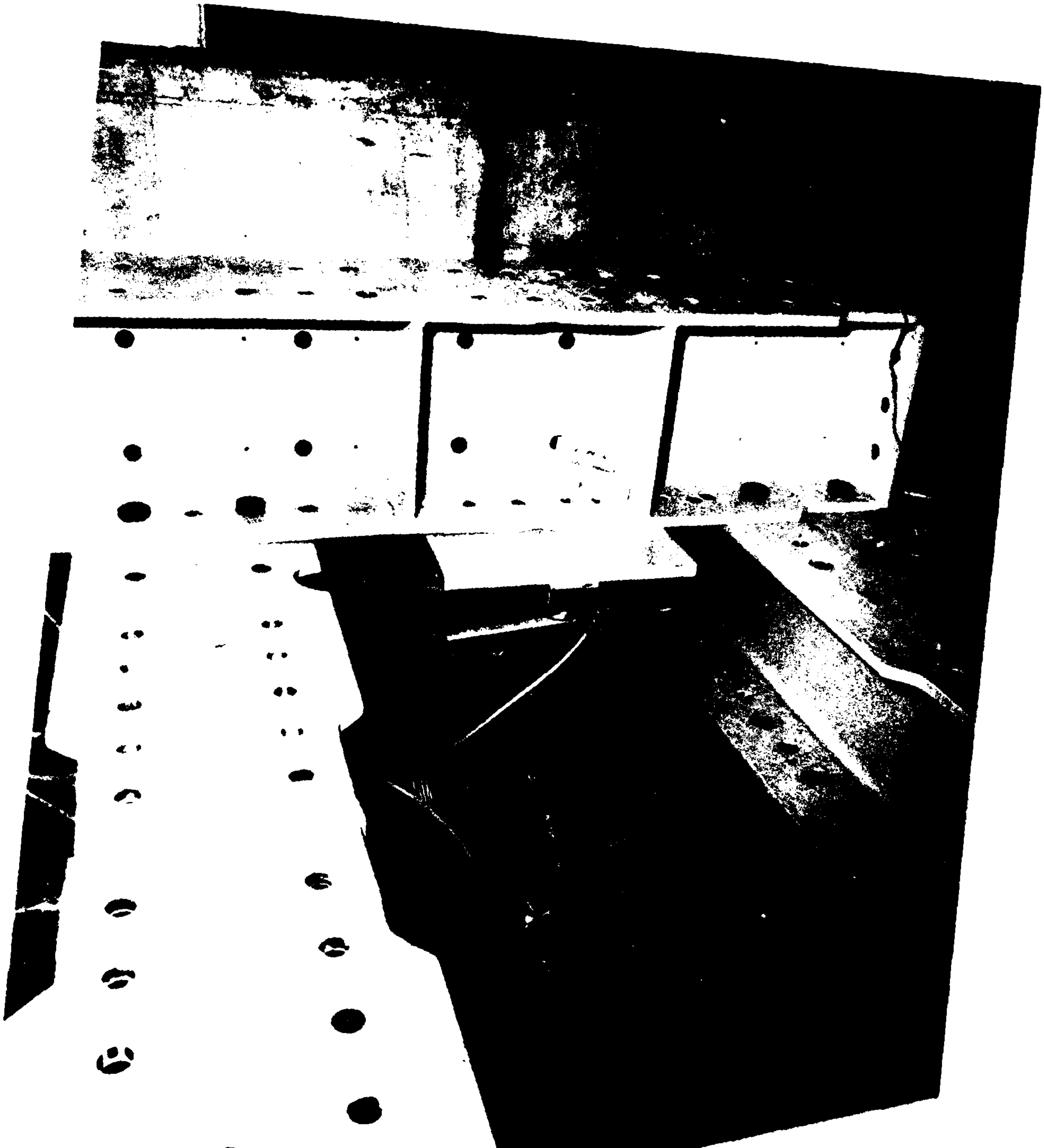


Figure B-4. Left Front Airspring—Boilerplate Test

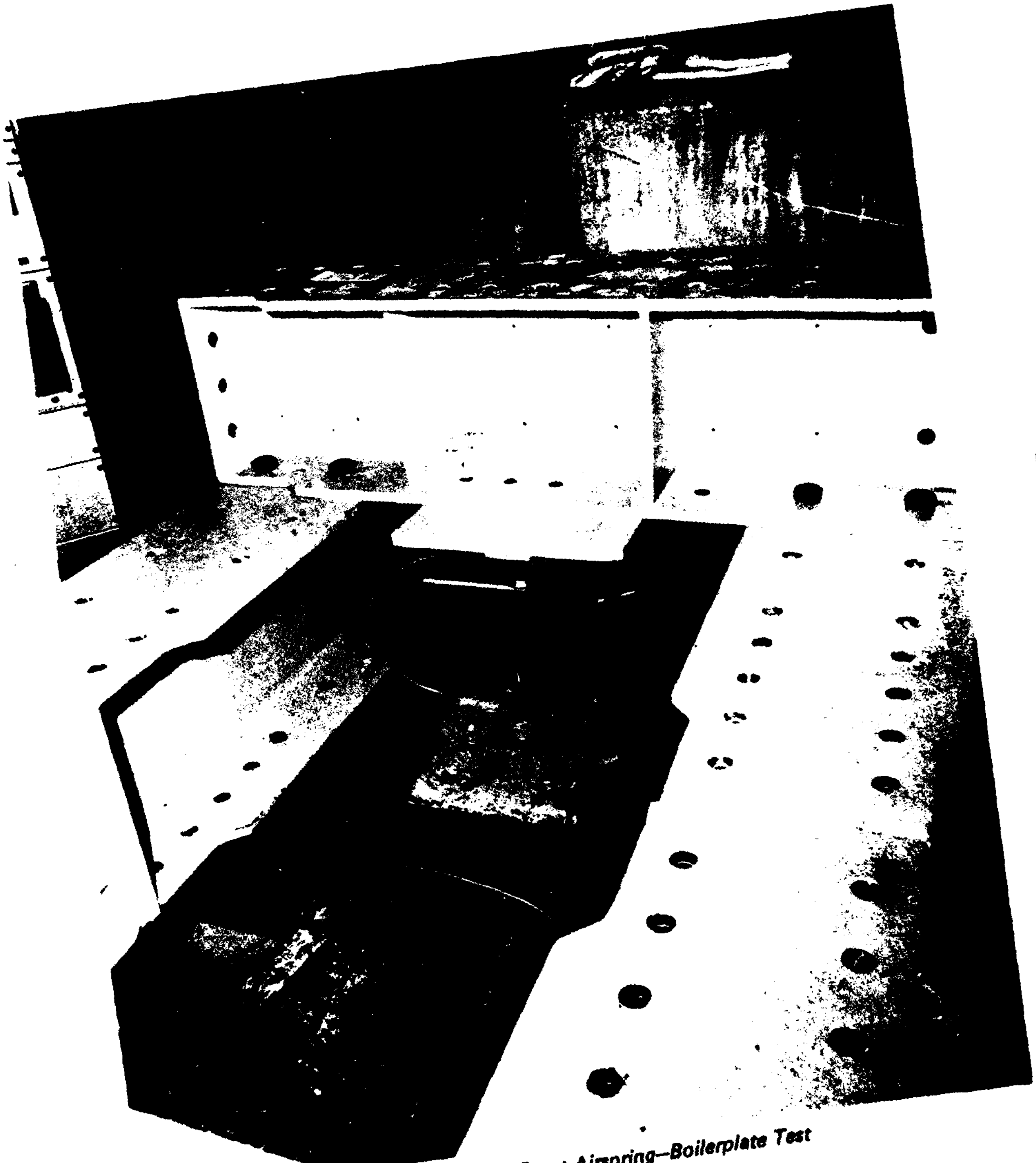


Figure B-5. Right Front Airspring—Boilerplate Test

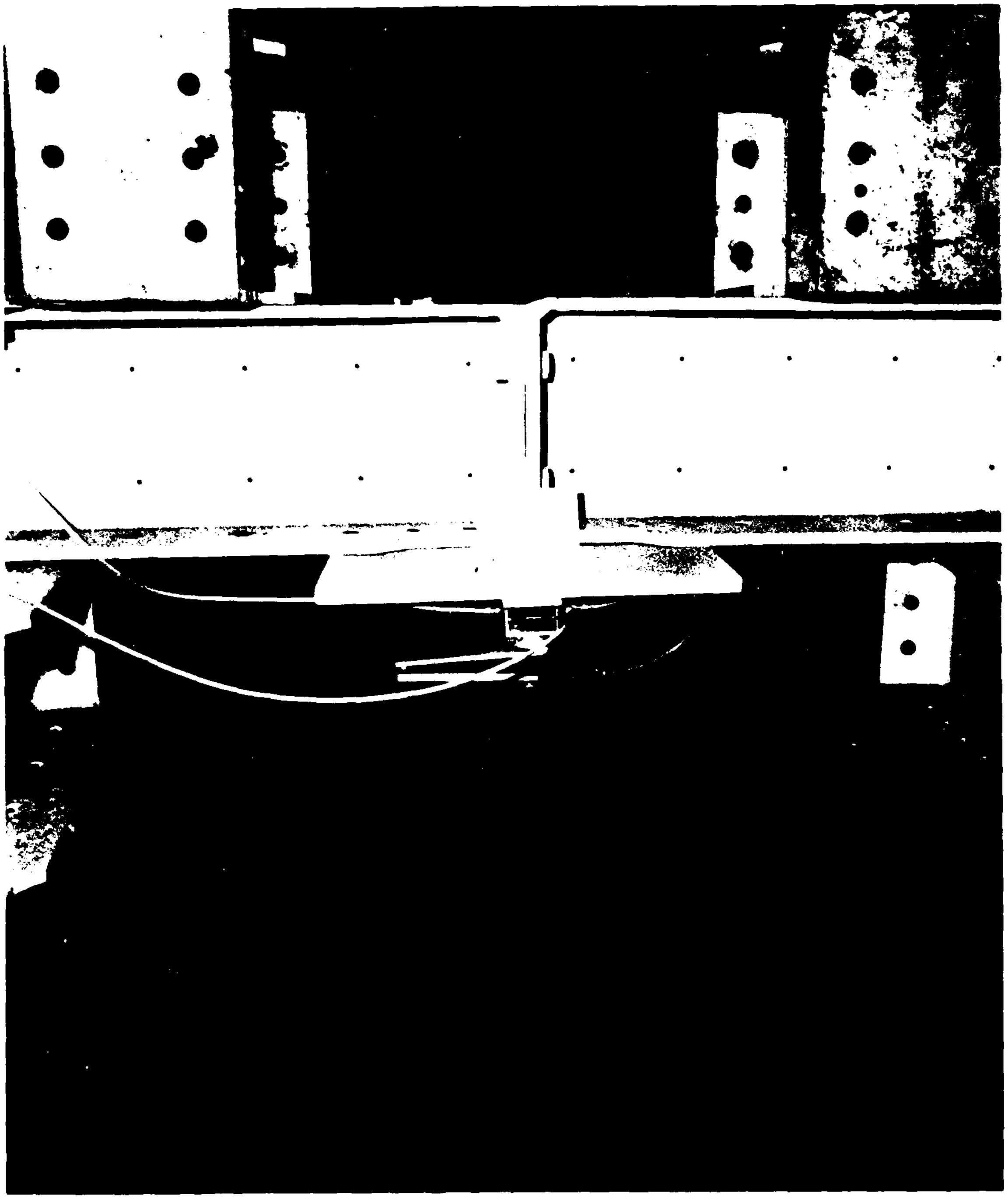


Figure B-6. Aft Airspring—Boilerplate Test

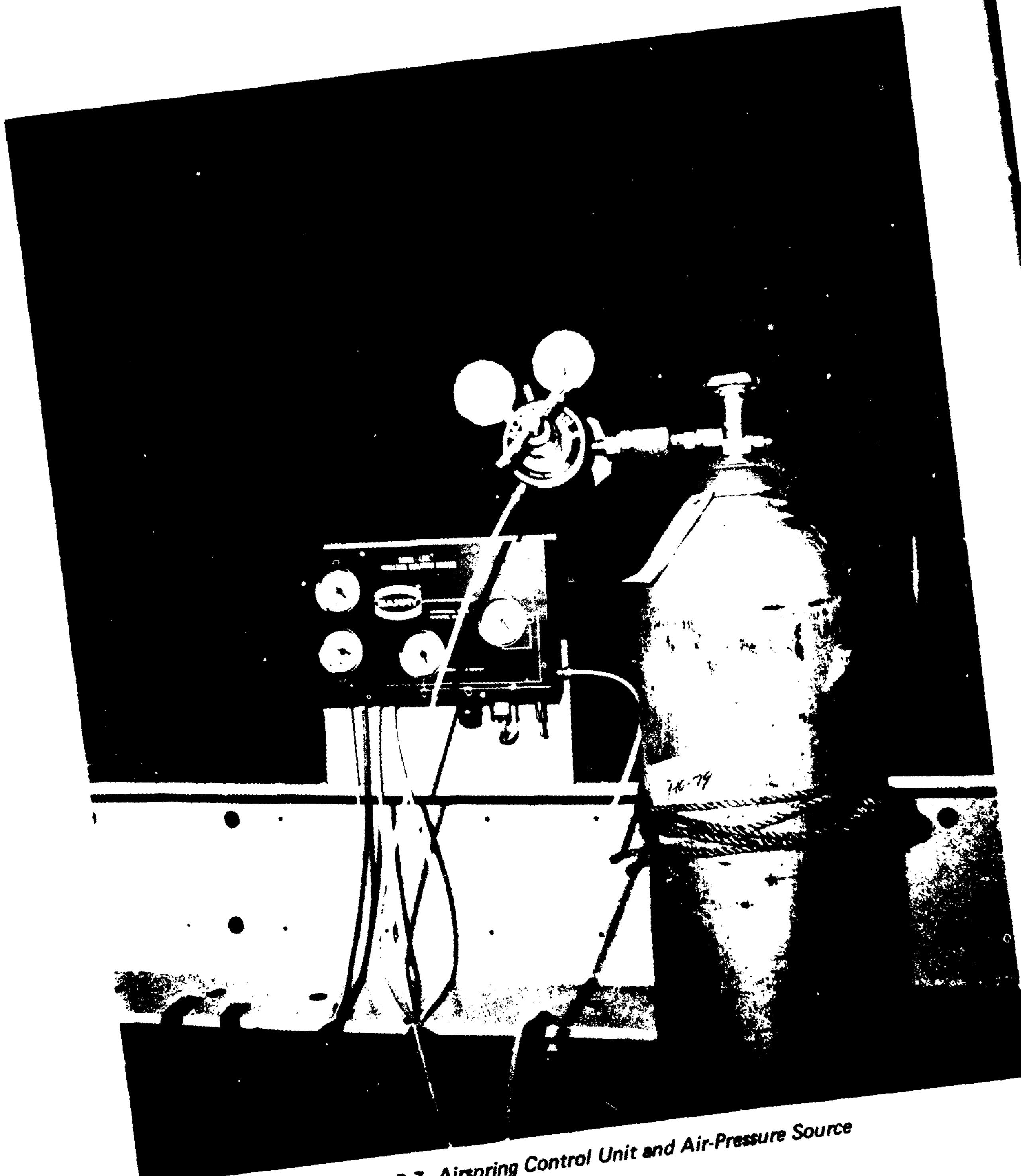


Figure B-7. Airspring Control Unit and Air-Pressure Source

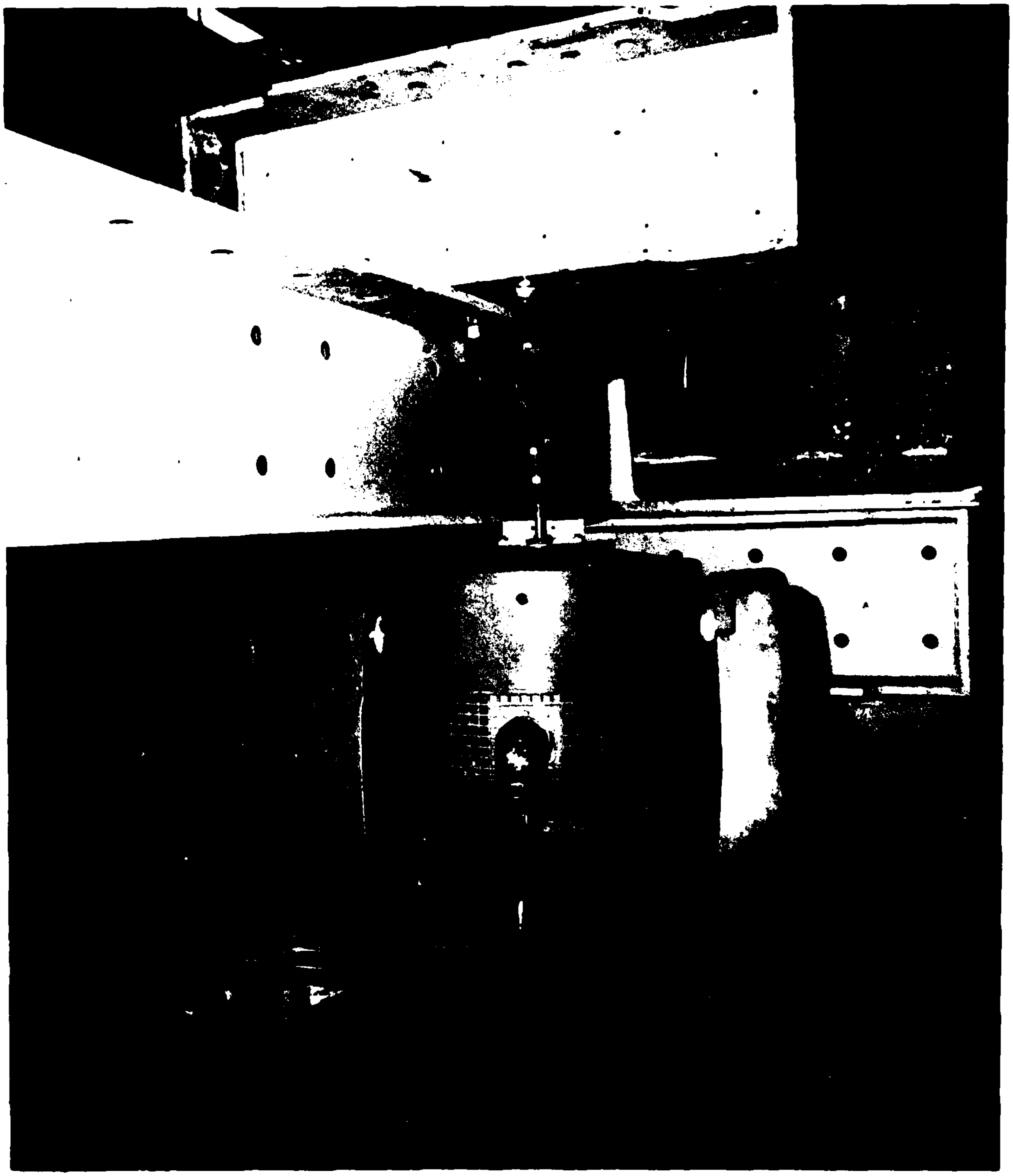


Figure B-8. Shaker Installation—Boilerplate Test

APPENDIX C

SUMMARY CHART - INDUSTRY INTERVIEWS

		Company																						
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Reason for GVT	Comparison with flutter model		✓	✓	✓	✓	✓	✓	✓		✓		✓			✓	✓	✓	✓	✓	✓	✓		✓
	Development of mass, stiffness, damping		✓		✓					✓	✓	✓						✓	✓			✓		
	Substructure modeling		✓	✓					✓									✓						
	Troubleshooting		✓	✓	✓	✓	✓	✓	✓			✓	✓	✓	✓			✓	✓	✓		✓	✓	✓
	Research		✓						✓	✓		✓	✓	✓	✓			✓	✓	✓			✓	
	Other	✓	✓		✓							✓		✓	✓				✓					
Test requirements	Frequencies	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓
	Normal mode shapes	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓
	Complex mode shapes		✓							✓	✓		✓			✓		✓				✓	✓	
	Damping	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓
	Generalized mass, stiffness, damping		✓		✓				✓					✓	✓			✓	✓			✓		
	Transfer functions		✓								✓		✓			✓		✓						
	Frequency response functions		✓		✓	✓	✓		✓		✓	✓	✓		✓	✓		✓	✓	✓		✓	✓	
	Coherence plots		✓		✓		✓				✓		✓		✓	✓		✓	✓			✓	✓	
	Orthogonality check		✓		✓			✓	✓		✓	✓			✓	✓			✓	✓	✓	✓		✓
	Other		✓		✓																			
Excitation techniques	Single shaker, single D.O.F.		✓						✓	✓	✓	✓	✓	✓	✓	✓				✓		✓		
	Single shaker, multiple D.O.F.		✓				✓			✓	✓	✓	✓		✓			✓	✓	✓		✓	✓	
	Multiple shaker, single D.O.F.	✓	✓	✓	✓	✓	✓	✓	✓			✓	✓	✓	✓	✓			✓	✓	✓	✓		✓
	Multiple shaker, multiple D.O.F.											✓												
	Other		✓								✓													

Summary Chart - Industry Interviews

		Company																						
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Excitation signal	Sinusoidal	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓
	Periodic		✓										✓		✓				✓			✓	✓	
	Random		✓							✓	✓	✓	✓		✓	✓		✓	✓	✓		✓	✓	
	Random transient		✓				✓								✓			✓	✓				✓	
	Transient		✓									✓			✓			✓	✓	✓		✓	✓	
	Other		✓				✓				✓	✓							✓	✓			✓	
Data acquisition techniques	Roving response transducers	✓	✓	✓		✓	✓	✓		✓	✓		✓	✓	✓						✓	✓	✓	✓
	L.T. 100 fixed response tranducers	✓	✓	✓			✓				✓			✓	✓			✓			✓	✓		✓
	G.T. 100 fixed response transducers		✓		✓				✓	✓		✓			✓	✓		✓	✓	✓	✓	✓		
	Other																							
Parameter estimation techniques	Single D.O.F.	✓	✓		✓		✓			✓			✓	✓	✓	✓				✓		✓	✓	
	Single D.O.F. with residuals		✓							✓					✓				✓	✓		✓	✓	
	Multiple D.O.F.		✓							✓		✓	✓							✓		✓	✓	
	Multiple D.O.F. with residuals		✓				✓			✓	✓	✓	✓			✓				✓		✓	✓	
	Other					✓			✓															
Test item support	Fixed	✓	✓	✓					✓						✓			✓	✓	✓				
	Free-free		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓			✓	✓	✓	✓	✓	✓	✓
	On landing gear	✓	✓	✓					✓		✓							✓	✓			✓	✓	
	other		✓								✓													

Summary Chart - Industry Interviews (Continued)

		Company																						
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Chronic problems	Closely coupled modes	✓	✓	✓		✓	✓		✓	✓	✓	✓	✓	✓	✓	✓		✓	✓		✓	✓	✓	✓
	Local modes		✓										✓	✓		✓							✓	
	Determination of normal mode		✓	✓			✓	✓						✓	✓	✓						✓		
	Orthogonality check							✓								✓					✓			
	Non-linearities	✓	✓						✓	✓			✓			✓		✓	✓			✓		
	Test time window	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓		✓			✓		✓	✓	✓		✓
	Test expense		✓			✓				✓												✓	✓	✓
	Other		✓					✓				✓								✓		✓	✓	
Non-linearities	Free-play	✓	✓	✓		✓			✓		✓	✓	✓		✓	✓	✓	✓	✓			✓	✓	
	Buckling	✓	✓	✓							✓	✓				✓			✓	✓		✓		
	Friction		✓			✓			✓	✓	✓	✓				✓	✓	✓	✓	✓		✓	✓	
	Hardening spring	✓	✓							✓	✓	✓							✓		✓			✓
	Softening spring		✓								✓													
	Other		✓												✓									
Treatment of non-linearities	Linearize	✓	✓			✓			✓	✓	✓	✓						✓	✓	✓		✓	✓	
	Document force relationships	✓	✓			✓		✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	Other		✓																					

Summary Chart - Industry Interviews (Concluded)

APPENDIX D

PRINCIPAL TOPICS - MOST SIGNIFICANT LITERATURE

Author	Date	Ref. No.	Test theory	Parameter estimation theory	Equipment description	Simplified test results	Actual test results	Survey of techniques
Asher	1968	6	X					
Asher	1967	7	X			X		
Beatrix	1973	11	X		X			
Berman	1971	14		X		X		
Bishop	1963	16	X	X				X
Brown	1977	25					X	X
Craig	1974	34	X			X		
Cromer	1978	36	X				X	
Dat	1975	37	X	X	X			
DeVeubeke	1956	45	X			X		
DeVries	1967	47	X					
Flannelly	1972	59		X				X
Hallauer	1978	70	X			X		
Halvorsen	1977	71	X			X		
Hamma	1976	73						
Hanks	1979	75					X	
Hawkins	1967	79						
Ibanez	1976	86	X					
Ibrahim	1978	87						
Ibrahim	1977A	88	X	X				
Johnston	1978	94					X	X
Kennedy	1947	96		X				
Klosterman	1971	99		X		X	X	
Klosterman	1975A	104		X	X			
Leppert	1976	111						X
Lweis	1960	112	X		X	X		
Link	1978	113	X	X		X		
Morosow	1978	127	X					
Mustain	1976	129						X
Natke	1976	136						
Nguyen	1976	138	X				X	X
Niedbal	1976	140						
Olsen	1977	144					X	
Pendered	1963A	147				X		X
Pendered	1963C	149		X		X		X
Potter	1975	157		X				
Ramsey	1975A	161		X				
Ramsey	1976	162				X		X
Richardson	1974	170		X		X		
Richardson	1976	172		X		X		
Stillard		183	X					
Sloane	1975	187	X	X	X			
Smith	1975	188			X		X	
Smith	1972B	190	X		X	X		
Stahle	1968	194	X		X	X		
Traill-Nash	1968	206	X					
Van Loon	1974	208		X			X	X
Wada	1975	210					X	
Woodcock	1963	218		X				
Brown	1979	222		X				X

Principal Topics - Most Significant Literature

APPENDIX E

SUMMARY CHART - FULL BIBLIOGRAPHY

Author	Date	Ref. No.	Survey of Modal techniques	Comparison of Modal techniques SPE-FRA VS MPE-SD	Modal parameter estimation	Modal parameter estimation MDOF	Test results SPE-FRA	Test results MPE-SD	Test theory SPE-FRA	Test theory MPE-SD	Noncon-ventional Modal	Equipment description
Abrahamson	1977	1					X					
Allemang	1978	2					X					
Anderson	1971	3						X				
Angellini	1976	4						X				
Archer	1968	5	X									
Asher	1958	6								X		
Asher	1967	7								X		
Bailey	1971	8						X				
Ballard	1969	9										
Barden	1975	10										X
Beatrix	1973	11								X		
Bendat	1976	12									X	
Bennett	1976	13				X						
Berman	1971	14							X			
Berman	1973	15									X	
Bishop	1963	16	X		X	X				X		
Blanchard	1977	17						X				
Bouche	1975	18										X
Bouche	1966	19										X
Bowles	1972	20				X						
Breitbach	1973	21			X					X		
Breitbach	1976	22						X				
Broadbend	1968	23			X							
Brown	1978	24	X				X					
Brown	1977	25					X		X			
Budd	1971	26						X				X
Budd	1969	27										X
Caughey	1960	28							X	X		
Cheng	1969	29										X
Clarkson	1965	30				X						
Collins	1974	31				X						
Collins	1972	32				X						
Coupry	1977	33				X				X		
Craig	1974	34								X		
Cromer	1978	35				X			X			
Curtis	1978	36						X				
Dat	1975	37	X	X								X
Dat	1973A	38										
Dat	1974A	39								X		
Dat	1973B	40				X						
Dat	1973C	41										
Dat	1974B	42				X			X			
Dat	1974C	43										
Degener	1977	44					X					
DeVeubeke	1966	45								X		
DeVeubeke	1976	46								X		

Summary Chart - Full Bibliography

Author	Date	Ref. No.	Survey of Modal techniques	Comparison of Modal techniques SPE-FRA VS MPE-SD	Modal parameter estimation	Modal parameter estimation MDOF	Test results SPE-FRA	Test results MPE-SD	Test theory SPE-FRA	Test theory MPE-SD	Noncon-ventional Modal	Equipment description
DeVries	1967	47								X		
Dixon	1967	48										X
Dodds	1975	49									X	
Durrani	1972	50							X			
Elenevskii	1976	51										X
Enocheon	1968	52							X			
Enocheon	1976	53							X			
Ewing	1972	54							X			
Ewins	1975	55							X			
Favour	1972	56							X			
Feix	1975	57	X	X				X		X		
Fillod	1978	58								X		
Flannelly	1972	59				X						
Flannigan	1973	60					X					
Fourney	1968	61							X			
Fowler	1978	62					X					
Freeland	1969	63						X				
Gaukroger	1974	64				X						
Gordon	1977A	65					X					
Gordon	1977B	66					X					
Goyder	1976	67										
Gravitz	1958	68				X						
Haidl	1976	69										
Hallauer	1978	70								X		
Halvorsen	1977	71							X			
Hamma	1978	72										
Hamma	1976	73	X	X								
Hammond	1976	74				X						
Hanks	1979	75		X								
Harting	1972	76							X			
Hasselman	1976	77								X		
Hawkins	1965	78										X
Hawkins	1967	79										X
Heizman	1972	80										X
Hewlett-Packard	1976	81										X
Hewlett-Packard		82				X						
Hoberock	1972	83				X						
Hoerner	1969	84				X						
Hunter	1968	85								X		
Ibanez	1976	86								X		
Ibrahim	1978	87				X					X	
Ibrahim	1977A	88									X	
Ibrahim	1977B	89									X	
Imes	1978	90					X					
Ip		91										
Ismail	1974	92							X			

Summary Chart - Full Bibliography (Continued)

Author	Date	Ref. No.	Survey of Modal techniques	Comparison of Modal techniques SPE-FRA VS MPE-SD	Modal parameter estimation	Modal parameter estimation MDOF	Test results SPE-FRA	Test results MPE-SD	Test theory SPE-FRA	Test theory MPE-SD	Noncon-ventional Modal	Equipment description
Jennings	1976	93					X		X			
Johnston	1978	94		X			X	X				
Kana	1977	95					X					
Kennedy	1947	96			X							
Kiessling	1978	97									X	
Kiessling	1975	98										
Klosterman	1971	99							X			
Klosterman	1973	100					X					
Klosterman	1972A	101					X					
Klosterman	1972B	102					X					
Klosterman	1976	103					X					
Klosterman	1975A	104					X					
Klosterman	1975B	105					X					
Knauer	1975	106					X					
Laidlaw	1968	107					X					
Langworthy	1972	108										
Lenz	1975	109				X						
Leondis	1974	110						X				
Leppert	1976	111		X			X	X				
Lewis	1960	112								X		
Link	1978	113									X	
Linscott	1976	114					X					
Ludwig	1972	115										X
MacKenzie	1974	116					X					
Mahalingam	1967	117									X	
Mahalingam	1975	118									X	
Mahalingam	1976	119									X	
Mahalingam	1973	120									X	
Mahalingam	1974	121							X	X		
Marchand	1974	122				X						
Marples	1973	123			X							
Merritt	1977	124									X	
Mirimand	1976	125							X			
Morosow	1977	126								X		
Morosow	1978	127								X		
** *128 **	1972	128					X					
Mustain	1976	129	X									
Muster	1973	130							X			
McConnell	1969	131							X	X		
McGrew	1969	132				X						
Natke	1972	133										
Natke	1975	134										
Natke	1973	135										
Natke	1976	136	X									
Neuman	1974	137					X					
Nguyen	1976	138								X		

Summary Chart - Full Bibliography (Continued)

Author	Date	Ref. No.	Survey of Modal techniques	Comparison of Modal techniques SPE-FRA VS MPE-SD	Modal parameter estimation	Modal parameter estimation MDOF	Test results SPE-FRA	Test results MPE-SD	Test theory SPE-FRA	Test theory MPE-SD	Noncon-ventional Modal	Equipment description
Nichols	1973	139						X				
Niedbal	1976	140	X									
Nissim	1967	141									X	
Noonan	1968	142									X	
North	1967	143						X				
Olsen	1977	144					X					
Ottens	1975	145						X				
Paramenter	1973	146							X			
Pendered	1963A	147			X				X	X		
Pendered	1963B	148							X	X		
Pendered	1963C	149			X				X	X		
Peterson	1977	150					X					
Piazzoli	1967	151										
Piazzoli	1976	152										
Piazzoli	1977	153										
Potter	1976	154										
Potter	1977	155									X	
Potter	1974	156				X						
Potter	1975	157							X			
Potter	1972	158							X			
Raney	1969	159									X	
Rades	1975	160			X							
Ramsey	1975A	161							X			
Ramsey	1976	162							X			
Ramsey	1975B	163							X			
Repin	1976	164										
Ratz	1975A	165										X
Ratz	1975B	166										X
Reiter	1975	167										X
Reveman	1970	168							X			
Richardson	1975A	169							X			
Richardson	1974	170							X			
Richardson	1975B	171							X			
Richardson	1976	172							X			
Roberts	1971	173					X		X			
Roberts	1975	174							X			
Rodden	1967	175									X	
Ross	1971	176				X						
Rucker	1976	177					X					
Ryneveld	1974	178										
Salyer	1973	179						X		X		
Scharton	1969	180										
Schiff	1972	181				X						
Schmitz	1974	182							X			
Sillard		183								X		
Sisson	1973	184					X					

Summary Chart - Full Bibliography (Continued)

Author	Date	Ref. No.	Survey of Modal techniques	Comparison of Modal techniques SPE-FRA VS MPF-SD	Modal parameter estimation	Modal parameter estimation MDOF	Test results SPE-FRA	Test results MPE-SD	Test theory SPE-FRA	Test theory MPE-SD	Noncon-ventional Modal	Equipment description
Skingle	1973	185			X							
Skopowski	1969	186						X				
Sloane	1975	187							X			
Smith	1975	188								X		X
Smith	1972A	189								X		
Smith	1972B	190								X		
Smyslov	1972	191						X				
Soovere	1976	192				X						
Spectral Dynmcs	1976	193										
Stahle	1958	194			X	X						
Stahle	1962	195			X	X						
Stahle	1978	196		X								
Stroud	1976	197										X
Strutz	1976	198					X					
Su	1972	199								X		
Sugivra	1975	200										
Suzuki	1975	201									X	
Targoff	1976	202				X						
Taylor	1967	203								X		X
Thoren	1972	204				X						
Tiltov	1973	205										X
Traill-Nash	1958	206								X		
Van Brussel	1975	207					X					
Van Loon	1974	208							X			
Viswanathan	1974	209										
Wada	1975	210						X				
Wada	1974	211						X				
Weisman	1975	212						X				
White	1976	213							X			
White	1969	214							X			
White	1971	215							X			
White	1972	216							X			
White	1976	217										
Wookcock	1963	218			X							
Yeh	1973	219										
Young	1969	220				X						
Zimmerman	1977	221									X	
Brown	1979	222			X	X						
Gold	1979	223										
Wiley	1979	224										

Summary Chart - Full Bibliography (Concluded)

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